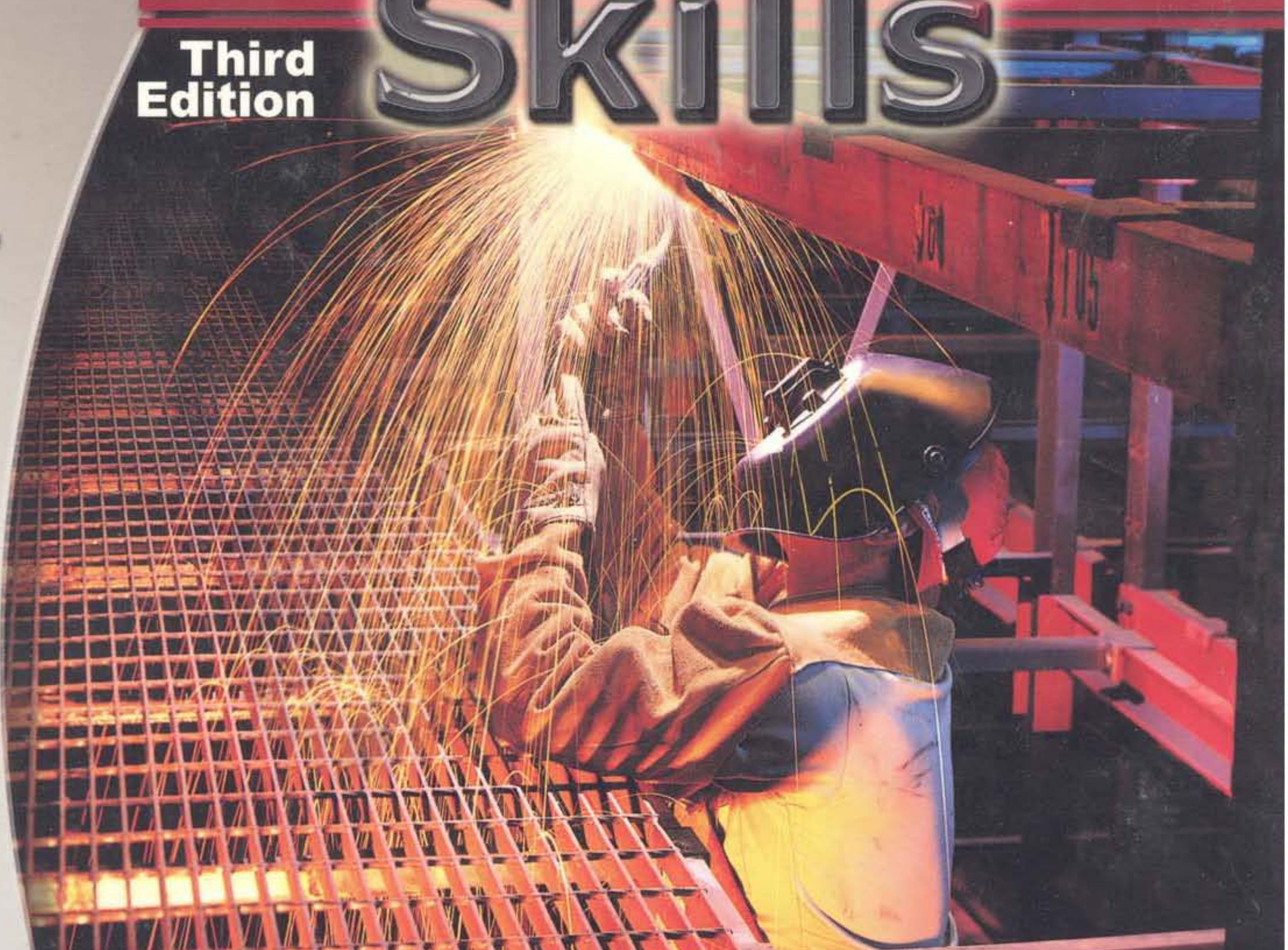
Welding Skills

Third Edition



an atp publication

B. J. Moniz
R. T. Miller

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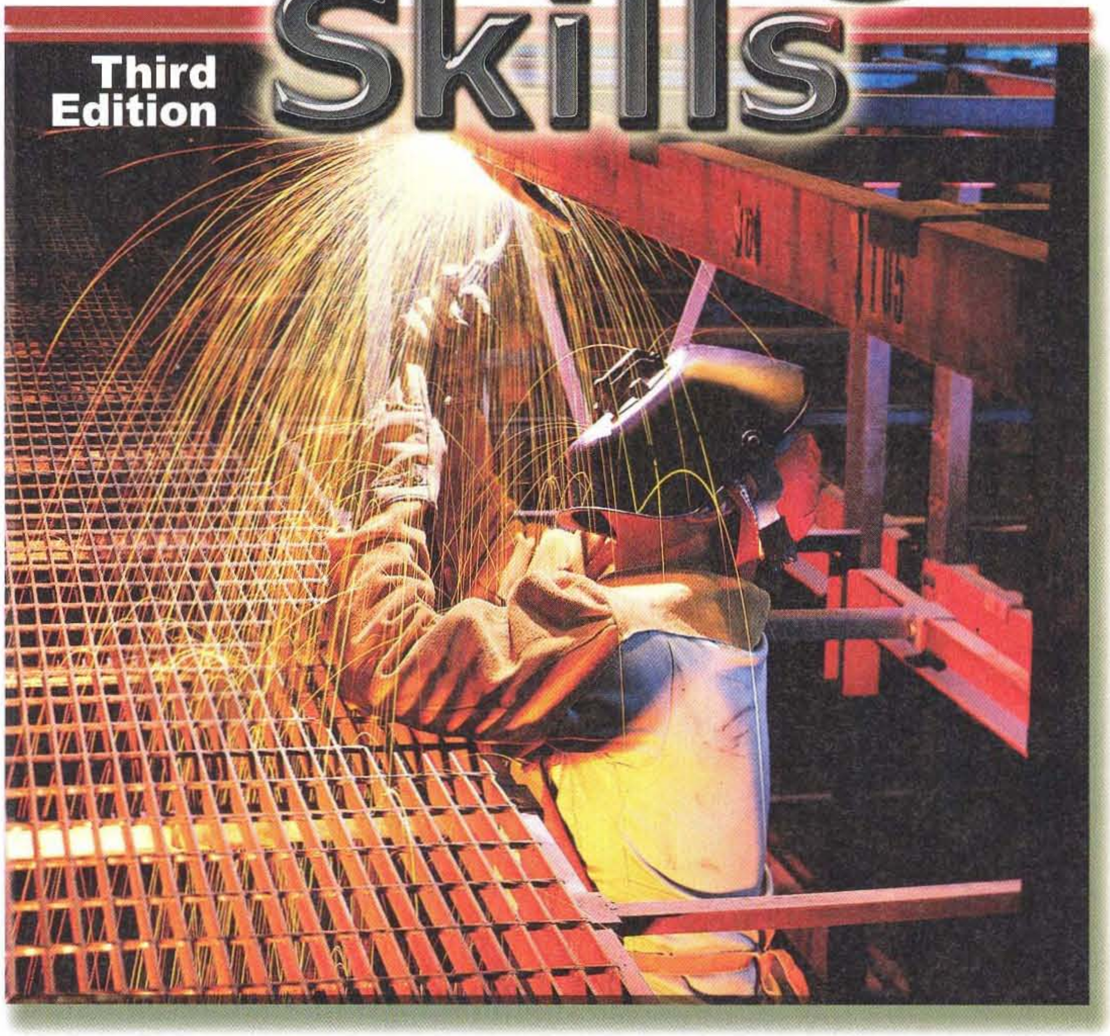

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B. J. Moniz
R. T. Miller

Welding Skills, 3rd Edition and CD-ROM contain welding procedures commonly practiced in industry. Specific procedures vary from plant to plant and must be performed by a qualified person. For maximum safety, always refer to specific manufacturer recommendations; insurance regulations; specific plant procedures; applicable federal, state, and local regulations; and any authority having jurisdiction.

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Introduction

Welding Skills, 3rd Edition, is the product of an extensive revision effort to address all aspects of the welding trade and the latest welding technology. Now in full color, this comprehensive text has been completely updated and expanded to continue the tradition of an industry-leading instructional tool. A new contemporary design, detailed illustrations, descriptive photographs, and concise text enhance the learning process. Step-by-step exercises, current AWS terminology, key points, and informative factoids supplement essential content throughout the text.

The Third Edition builds on the quality of previous editions and offers valuable new content contributed by Bert J. Moniz. Having over 37 years of experience in metallurgy and many facets of welding, Mr. Moniz currently serves as Materials Engineering Consultant with the DuPont Company. In his current position, he is involved with selecting materials for construction, fabrication, and failure analysis worldwide. He has taught related courses, authored books, and written and presented several papers. His hands-on knowledge and expertise are reflected throughout the text and in the development of new chapters covering:

- Repair Welding
- Metallography
- Weld Discontinuities
- Metal Identification
- Weldability of Common Metals
- Distortion Control
- Materials and Fabrication Standards and Codes

The text begins with an introduction to the welding process and welding in industry. Throughout the text an emphasis is placed on fundamental principles of welding processes, equipment, welder performance qualification, and weld evaluation and testing. The text also covers the latest technology in welding metallurgy, metal weldability, distortion control, robotics, and material standards and codes. Chapters in the text have been organized into eight sections to progressively enhance knowledge and skills. Safety procedures and potential health and safety hazards are covered in context with appropriate cautions and warnings. The Appendix contains reference material pertinent to the welding trade, and the Glossary provides definitions of welding terms introduced in the text.

The *Welding Skills,* 3rd Edition CD-ROM in the back of the book is a self-study aid designed to augment content included in the text. The CD-ROM includes a Quick Quiz™ for each section of the text, an Illustrated Glossary, Media Clips, Welding Resources, and related welding reference material. Information about using the CD-ROM is included on the last page of the book.

Welding Skills, 3rd Edition, is one of several high-quality training products available from American Technical Publishers, Inc. To obtain information about related training products, visit the American Tech web site at www.go2atp.com.

The Publisher

1 An Essential Skill

Welding is an efficient, dependable, flexible, and economical means of fabrication. Welding is widely used in industry as a principal means of fabricating and repairing metal products. Welding can lower production costs by simplifying design and eliminating costly patterns and machining operations. Welding can also be used in repair operations and adding new metal to worn parts.

There are many opportunities for welders trained in welding techniques, materials, designs, and applications.

WHERE WELDING IS USED

Welding is the coalescence or joining together of metals, with or without a filler metal, using heat, and/or pressure. Bonding of metals during welding occurs through localized melting or microstructural changes at the interface between the metals. Welding is used throughout industry in building construction, aircraft manufacturing, and for automobile production. See Figure 1-1.

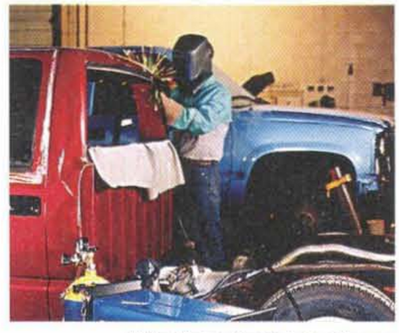
Welding is used extensively for the manufacture and repair of farm equipment, mining and refinery equipment, and jigs and fixtures; and in the construction of boilers, furnaces, and railway cars. Welding is also commonly used in the manufacture of products for household use, such as television sets, refrigerators, storage cabinets, and dishwashers. Construction of bridges and ships also commonly requires welding.

Nearly two-thirds of all welders work in the construction, transportation equipment, fabricated metal products, machinery, and motor vehicle and equipment industries.

Welding in Industry
Figure 1-1

The Lincoln Electric Company
CONSTRUCTION

Boeing Commercial Airplane Group
AVIATION



Miller Electric Manufacturing Company
AUTOMOTIVE

Figure 1-1. *Welding is used throughout industry to join metals efficiently and economically.*

DEVELOPMENT OF WELDING PROCESSES

Modern welding processes evolved from discoveries and inventions dating back to the year 2000 B.C. when forge welding was first used as a means of joining two pieces of metal. It was a crude process of joining metal by heating and hammering until the objects were fused together. Today, forge welding is used only in limited applications.

The combustion of a mixture of acetylene and oxygen produces a flame that is suitable for welding and cutting.

Acetylene gas was discovered in 1836 by Edmund Davy. When combined with oxygen, acetylene produced a flame suitable for welding and cutting. The application of heat generated from an electric arc between carbon electrodes was the basis for the arc welding process. Resistance welding, which also uses electricity, was also developed in the late 1800s and first used in the early 1900s.

One of the most significant developments at the time was the invention of an electrode that is consumed into the weld while providing heat from an arc (the shielded metal arc welding process). Modifications to the coating applied on the consumable electrode allowed greater applications for arc welding.

The primary duty of a welder using oxyfuel welding is to control and direct heat onto the edges of the metal to be joined.

Another improvement in the arc welding process was the addition of an inert shielding gas to protect the weld area from atmospheric contamination (the gas tungsten arc welding process). This proved to be an especially important process in welding magnesium and aluminum on World War II fighter planes. The electrode used was made out of tungsten and was not consumed into the weld. Originally, helium was used as a shielding gas, but was later replaced by the less expensive argon.

New developments in the field continue to address new requirements and applications in industry. Current welding processes are the product of continued refinements and variations of the welding processes discovered in the 1800s.

WELDING PROCESSES

The demands of a growing industrial economy during the 1800s spurred the development of modern welding processes. The welding process to be used for a particular job is determined by the following:

- type of metals to be joined
- costs involved
- nature of products to be fabricated
- production techniques used
- job location
- material appearance
- equipment availability
- welder experience

Welding processes used today are commonly classified as oxyfuel welding, arc welding, and resistance welding. See Figure 1-2.

In 1810, Sir Humphrey Davy discovered that an electric arc could be maintained at will by bringing two terminals of high voltage electricity near each other. The length and intensity could be varied by adjusting the voltage of the circuit.

Oxyfuel Welding

Oxyfuel welding (OFW) is a group of welding processes that use heat from the combustion of a mixture of oxygen and a fuel for welding. Acetylene, methylacetylene-propadiene stabilized (MAPP) gas, propane, natural gas, hydrogen, or propylene may be used. The heat is obtained from the combustion of a combustible gas and oxygen. OFW welding processes are used with or without filler metal. If filler metal is not used in the joint, the weld is autogenous. An *autogenous weld* is a fusion weld made without filler metal.

Oxyacetylene welding is the most commonly used oxyfuel process. *Oxyacetylene welding (OAW)* is an oxyfuel welding process that uses acetylene as the fuel gas.

Welding Processes
Figure 1-2

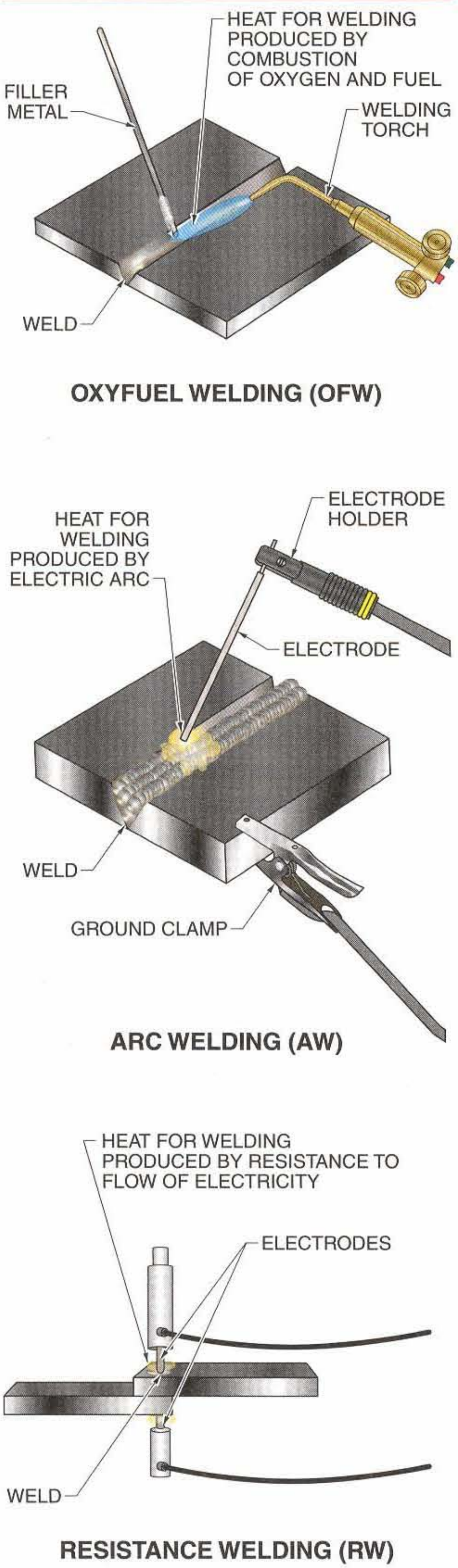


Figure 1-2. *Welding processes are commonly classified as oxyfuel welding, arc welding, and resistance welding.*

Because of its flexibility and mobility, oxyacetylene welding is used in all metalworking industries, but is most commonly used for maintenance and repair work.

Arc Welding

Arc welding (AW) is a group of welding processes that produce coalescence of metals by heating them with an electric arc. The arc is struck between a welding electrode and the base metal. The welding electrode is a component of the welding circuit that terminates at the arc. The joint area is shielded from the atmosphere until it is cool enough to prevent the absorption of harmful impurities from the atmosphere.

AW is the most common method of welding metals. AW processes include shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), flux cored arc welding (FCAW), submerged arc welding (SAW), and plasma arc welding (PAW).

SMAW electrodes can be modified to allow for wider application of SMAW processes.

Shielded Metal Arc Welding. *Shielded metal arc welding (SMAW)* is an arc welding process in which the arc is shielded by the decomposition of the electrode coating. The electrode is consumed into the weld while providing heat from an electric arc. Variations in composition of the electrode coating allow different applications of the SMAW process.

Common applications of SMAW are in the fabrication of machinery and structural steel for buildings and bridges. SMAW is considered ideal for making storage and pressure vessels as well as for production-line products using standard commercial metals. SMAW is also used in repair work and in welding large structures.

Gas Tungsten Arc Welding. *Gas tungsten arc welding (GTAW)* is an arc welding process in which a shielding gas protects the arc between a nonconsumable (does

not become part of the weld) tungsten electrode and the weld area. GTAW uses a nonconsumable tungsten electrode and a shielding gas, usually helium or argon, for welding. The GTAW process can be used to weld using filler metal, or without filler metal to form an autogenous weld. GTAW is widely used for joining thin-wall tubing and depositing the root pass in pipe joints. GTAW produces a very high-quality weldment.

Gas Metal Arc Welding. *Gas metal arc welding (GMAW)* is an arc welding process that uses an arc between a continuous wire electrode and the weld pool. Argon is used as a shielding gas for nonferrous metals such as aluminum, and carbon dioxide/carbon dioxide mixtures (such as 75/25, 98/2) with argon are used as a shielding gas for steels. The GMAW process uses a continuously fed consumable wire, eliminating the need to stop and change electrodes. This has increased the popularity of GMAW in manufacturing.

FCAW uses a tubular electrode with flux in its core.

Flux Cored Arc Welding. *Flux cored arc welding (FCAW)* is an arc welding process that uses a tubular electrode with flux in its core. FCAW produces fast, clean welds with excellent appearance and high deposition rates, and the process can be automated.

Like GMAW, the primary benefit of FCAW over SMAW is the higher productivity rate possible with the continuous-feed system, which also results in lower production costs. FCAW is commonly used to weld carbon, low-alloy and stainless steels, and cast iron. Typical applications include field and shop fabrications.

Submerged Arc Welding. *Submerged arc welding (SAW)* is an arc welding process that uses an arc between a bare metal electrode and the weld pool. The electrode, arc, and weld pool are submerged in a granular flux poured on the base metal. SAW is limited to flat or low-curvature base metals. SAW produces high-quality weld metal with fast deposition rates. The weld surface is smooth with no spatter. SAW is automated and most often used to join thick metals requiring deep penetration, such as in heavy steel plate fabrication.

Plasma Arc Welding. *Plasma arc welding (PAW)* is an arc welding process that uses a constricted arc between a nonconsumable tungsten electrode and the weld pool (transferred arc), or between the electrode and constricting nozzle (non-transferred arc). Transferred arc PAW produces a deep, narrow, uniform weld zone and is suitable for almost any metal.

Transferred arc PAW is used for welding high-strength, thin metal. Non-transferred arc PAW is typically used for thermal spraying.

Resistance Welding

Resistance welding (RW) is a group of welding processes in which welding occurs from the heat obtained by resistance to the flow of current through the metals joined. A resistance welding machine fuses metals together by heat and pressure. RW is used to make localized (spot) or continuous (seam) joints. An advantage of resistance welding is its adaptability to rapid fusion of seams.

RW uses special fixtures and automatic handling equipment for the mass production of automobile bodies, electrical equipment, hardware, or other domestic goods. RW can be used for joining almost all steels, stainless steels, aluminum alloys, and some dissimilar metals.

OCCUPATIONAL OPPORTUNITIES IN WELDING

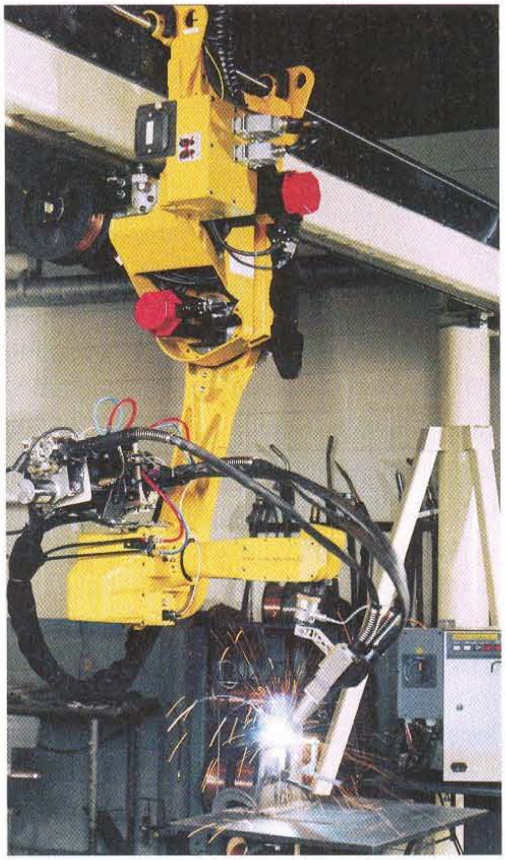
The widespread use of welding in American industry provides a constant source of employment for welders. According to the U.S. Department of Labor, there are approximately 588,000

persons employed as welders. Over half of these work in industries that manufacture durable goods such as transportation equipment, machinery, and household products. Many others work for construction firms and repair shops. A growing number of welders are required to operate automated and robotic welding machines.

Employment Outlook

Opportunities for those who desire to become welders differ by occupational specialty. A healthy economy and a need to replace experienced workers who leave the field create a demand for welders. Certified welders, especially those certified in more than one process, have better employment opportunities than non-certified welders.

Although many companies have automated some tasks traditionally performed manually, qualified welders are still required. Many automated welding machines and robots require a single operator overseeing multiple operations. However, fabrication and repair applications are still common in the welding industry. See Figure 1-3.



The Lincoln Electric Company

Figure 1-3. *Robotic welding machines are programmed to perform repetitive welds on mass-produced products and require supervision by a skilled welding machine operator.*

The need for certified welders continues to grow in the welding industry.

Training

Training to be a welder is available from different sources. Many schools offer comprehensive welding training programs. Company training programs can vary from a few months of on-the-job training to several years of formal training. Apprenticeship programs that include welder training are also available through unions such as the International Association of Bridge, Structural, Ornamental, and Reinforcing Iron Workers or the International Union of Operating Engineers (IUOE). Most employers prefer applicants who have some welding experience and courses in mathematics, mechanical drawing, metals, and blueprint reading.

Welders must have good manual dexterity, eyesight, and hand-eye coordination. They should be able to concentrate on detailed work for long periods and must be free of physical disabilities that would prevent them from bending, stooping, or working in awkward positions. Welders must also be able to lift 50 lb regularly and 100 lb occasionally.

Before being assigned to work where the quality and strength of the weld are critical, a welder generally has to pass a certification test given by an employer, government agency, or inspection authority. See Figure 1-4. Typically, welders are certified by an employer to perform specific welds. Recent efforts by the American Welding Society (AWS) allow certified welders to be listed on a national registry. The national registry assists employers in finding employees that have attained a particular skill level.

The American Welding Society (AWS) maintains a national registry of certified welders to assist employers in finding employees that have attained a particular skill level.

Figure 1-4. *Welders are certified by an employer, government agency, or inspection authority to perform specific welds.*

Job Classifications

Welding jobs differ in the degree of skill required. Welding machine operators can learn the required procedures in several hours, while welders may need years of on-the-job training to master their craft. A beginning welder usually starts on simple production jobs and gradually works up to higher levels of skill with experience.

Welders must have a working knowledge of metal properties and effects of heat on welded structures. They must also have an understanding of how materials are fabricated. Welders must be able to read detailed drawings, prepare the work area, control expansion and contraction forces, read welding symbols, recognize weld defects, and perform all tasks required to finish the welding job. A welder may be proficient in several welding task areas or a specific welding task. As a rule, the welder is always certified for the specific welding task required. Skilled welders may, by promotion, become inspectors or supervisors. Some of the principal job titles of welders include the following:

Welder Helper. Entry-level welder, cleans slag for Welder, positions workpieces, helps move materials.

Welder. Person who performs welding using the required process.

Welder Operator. Welder who operates automatic welding equipment, such as that found on automobile assembly lines.

Pipe Welder. Welder with additional training and certification in welding pipe.

Welding Layout and Set-up Person. Welder with printreading experience. Must prepare workpieces for welding.

Some welding personnel are required to oversee welder certification, instruction, and quality control. The following supervisory positions require additional training:

Welding Inspector. Certified welder who has undergone additional certification to work as an inspector.

Welding Supervisor. Person with good management skills who can effectively run a weld shop and maintain the required welding schedule and quality of workmanship. Welding supervisors must be knowledgeable about company standards and procedures.

Welding Instructor. Person employed by a high school, community college, vocational program, or apprenticeship program. Instructors must be certified to meet AWS standards.

Welding Engineer. Person with a college degree and professional certification qualified to specify necessary weld requirements.

The Lincoln Electric Company

The need for certified welders is growing as experienced welders leave the workforce.

POINTS TO REMEMBER

1. The combustion of a mixture of acetylene and oxygen produces a flame that is suitable for welding and cutting.
2. The primary duty of a welder using oxyfuel welding is to control and direct heat onto the edges of the metal to be joined.
3. SMAW electrodes can be modified to allow for wider application of SMAW processes.
4. FCAW uses a tubular electrode with flux in its core.
5. The need for certified welders continues to grow in the welding industry.
6. The American Welding Society (AWS) maintains a national registry of certified welders to assist employers in finding employees that have attained a particular skill level.

QUESTIONS FOR STUDY AND DISCUSSION

1. Name some manufacturing applications for which welding is commonly used.
2. What is the basis of the arc welding process?
3. Name the three common classifications of welding processes used today.
4. Define autogenous weld.
5. What is the most common welding method used for welding metals?
6. What is one difference between FCAW and GMAW?
7. What is transferred PAW typically used for? Non-transferred PAW?
8. List training programs that provide education for welders.
9. What are some skills that all welders should have?

Welding Safety

Every year, thousands of welders suffer injuries as a result of accidents that occur because proper safety precautions are not followed at the job site. Accidents occur because of indifference to regulations, lack of information, or carelessness. Any injury can be painful and can incapacitate a person, or lead to permanent disability or death.

Safety precautions are effective in reducing the occurrence of accidents at the job site. Safety means using common sense and avoiding serious accidents; and it has to be observed constantly. Established safety practices should be followed at all times. If good safety practices are consistently followed, an awareness of proper behavior is established that usually prevents mistakes.

JOB SITE SAFETY

Industry places a strong emphasis on safety in the workplace. A tremendous amount of time and effort is spent on safety training and awareness. The Occupational Safety and Health Administration (OSHA) standardizes safety practices for most types of work environments. The *Occupational Safety and Health Administration (OSHA)* is a federal agency that requires all employers to provide a safe environment for their employees. See Figure 2-1.

Employers are responsible for safety training at the job site and for ensuring that their employees are familiar with, and follow, OSHA regulations. Most companies have a comprehensive new-hire training program to cover the overall safety requirements of the company. Weekly safety meetings and/or toolbox talks are also held to discuss current safety topics and employee safety concerns, and to answer any employee questions. Attendance at these meetings is usually required and is beneficial for keeping current with company safety regulations. Safety meetings are a good way for employees to keep current about potential hazards that have arisen or to inform a supervisor about hazards they have noticed at the job site.

Weekly safety meetings are a convenient way for employers to discuss relevant job site safety issues and concerns.

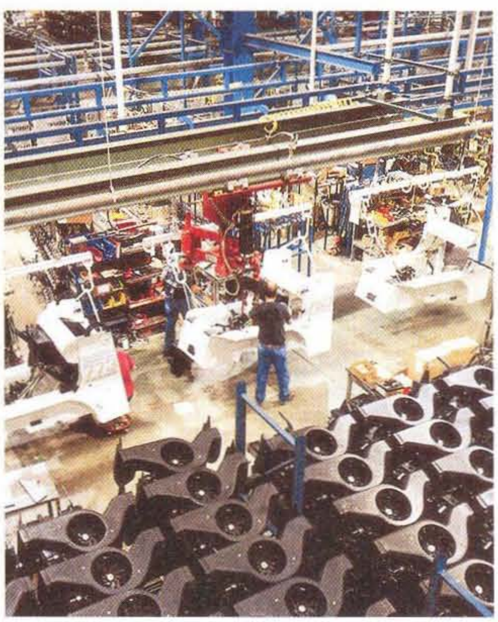


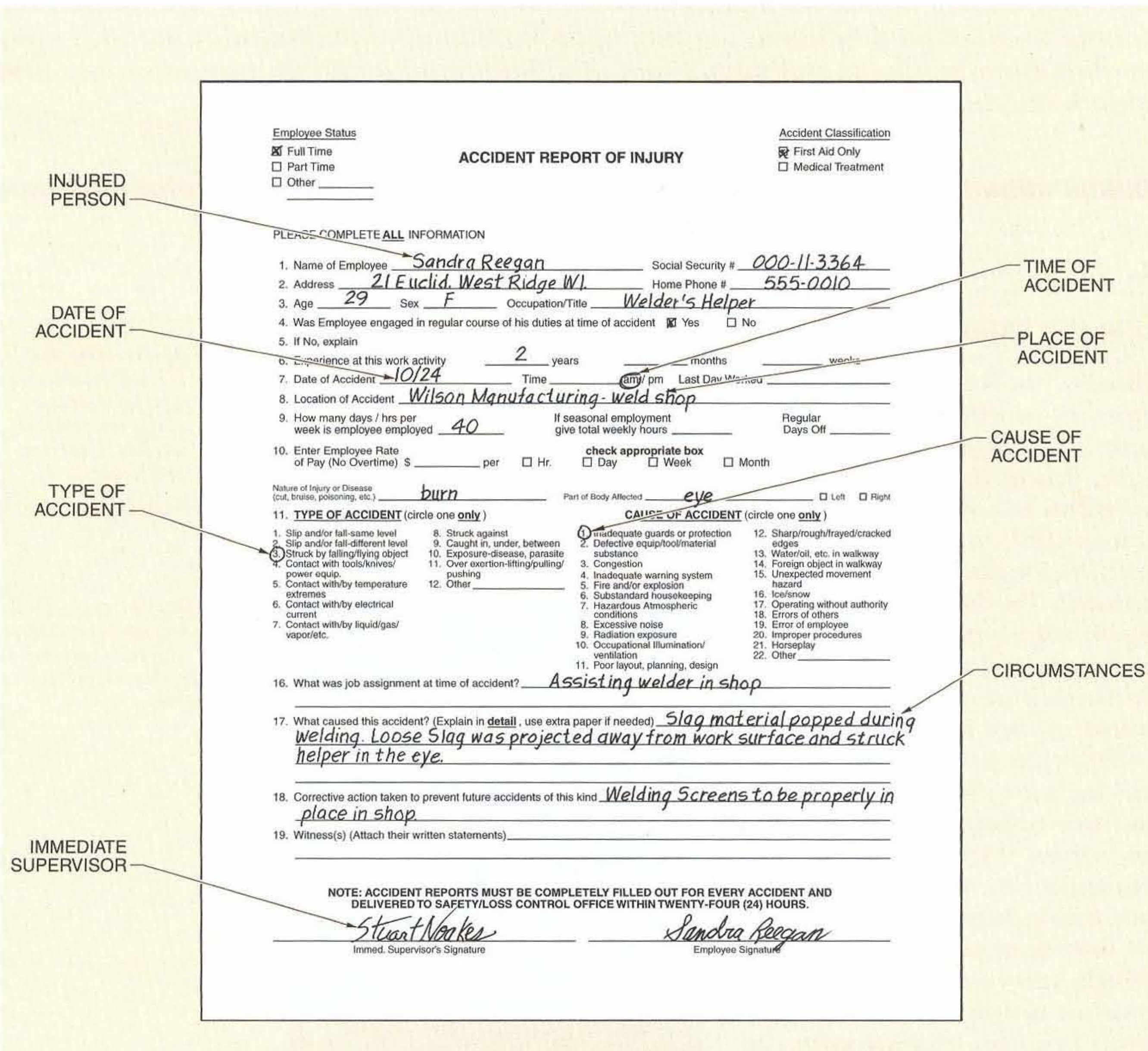
Figure 2-1. *The Occupational Safety and Health Administration (OSHA) requires employers to provide a safe work environment for employees.*

Reporting Accidents

According to the Bureau of Labor Statistics, approximately 26,000 welders per year are injured on the job site. Welders are exposed to health risks every day: the ultraviolet rays of the welding arc can injure the eyes or the skin; some gases produced by welding may be toxic and if breathed in may affect the lungs; and welding or cutting near flammable materials, or welding on containers that have held combustible materials, poses a fire risk.

While precautions must be taken to prevent injuries, accidents do happen. All accidents should be reported, regardless of how minor they may be. A small scratch might lead to a serious infection, or a minute particle lodged in the eye could result in a serious eye injury. Prompt attention to any injury usually minimizes the seriousness of the injury. See Figure 2-2.

Any job site where physical work is performed should have an established accident reporting procedure. Since this reporting procedure is in the best interest of the worker, it is irresponsible to ignore it or try to avoid reporting an accident. Instead, workers should become fully informed about what should be done and then take immediate action if an accident occurs.



Employee Status
☒ Full Time
☐ Part Time
☐ Other ______

ACCIDENT REPORT OF INJURY

Accident Classification
☒ First Aid Only
☐ Medical Treatment

PLEASE COMPLETE **ALL** INFORMATION

1. Name of Employee Sandra Reegan Social Security # 000-11-3364
2. Address 21 Euclid, West Ridge WI. Home Phone # 555-0010
3. Age 29 Sex F Occupation/Title Welder's Helper
4. Was Employee engaged in regular course of his duties at time of accident ☒ Yes ☐ No
5. If No, explain
6. Experience at this work activity 2 years ____ months ____ weeks
7. Date of Accident 10/24 Time ____ am/pm Last Day Worked ____
8. Location of Accident Wilson Manufacturing - weld shop
9. How many days / hrs per week is employee employed 40 If seasonal employment give total weekly hours ____ Regular Days Off ____
10. Enter Employee Rate of Pay (No Overtime) $ ____ per **check appropriate box** ☐ Hr. ☐ Day ☐ Week ☐ Month

Nature of Injury or Disease (cut, bruise, poisoning, etc.) burn Part of Body Affected eye ☐ Left ☐ Right

11. **TYPE OF ACCIDENT** (circle one **only**)
1. Slip and/or fall-same level
2. Slip and/or fall-different level
3. Struck by falling/flying object
4. Contact with tools/knives/power equip.
5. Contact with/by temperature extremes
6. Contact with/by electrical current
7. Contact with/by liquid/gas/vapor/etc.
8. Struck against
9. Caught in, under, between
10. Exposure-disease, parasite
11. Over exertion-lifting/pulling/pushing
12. Other ______

CAUSE OF ACCIDENT (circle one **only**)
1. Inadequate guards or protection
2. Defective equip/tool/material substance
3. Congestion
4. Inadequate warning system
5. Fire and/or explosion
6. Substandard housekeeping
7. Hazardous Atmospheric conditions
8. Excessive noise
9. Radiation exposure
10. Occupational Illumination/ventilation
11. Poor layout, planning, design
12. Sharp/rough/frayed/cracked edges
13. Water/oil, etc. in walkway
14. Foreign object in walkway
15. Unexpected movement hazard
16. Ice/snow
17. Operating without authority
18. Errors of others
19. Error of employee
20. Improper procedures
21. Horseplay
22. Other ______

16. What was job assignment at time of accident? Assisting welder in shop
17. What caused this accident? (Explain in **detail**, use extra paper if needed) Slag material popped during welding. Loose Slag was projected away from work surface and struck helper in the eye.
18. Corrective action taken to prevent future accidents of this kind Welding Screens to be properly in place in shop
19. Witness(s) (Attach their written statements) ______

NOTE: ACCIDENT REPORTS MUST BE COMPLETELY FILLED OUT FOR EVERY ACCIDENT AND DELIVERED TO SAFETY/LOSS CONTROL OFFICE WITHIN TWENTY-FOUR (24) HOURS.

Stuart Noakes
Immed. Supervisor's Signature

Sandra Reegan
Employee Signature

Figure 2-2. *An accident report form must be filled out to accurately reflect the events of an accident, list injuries, and detail job hazards that may need attention.*

Work Behavior

Occasionally, workers may engage in what might appear to be harmless pranks. However, there are many recorded incidents where a prank ended in serious injury. Any form of horseplay in a shop is dangerous and can lead to an accident. Most work areas are reasonably safe if proper work precautions are taken, but no one is safe if good work attitudes are ignored.

SAFE EQUIPMENT OPERATION

Welding equipment should not be used unless exact operating instructions have been received and understood. Manufacturer recommendations should be followed at all times. Attempting to operate a piece of equipment without instruction may not only damage the equipment, it could result in a serious injury.

Operators of equipment should wear appropriate personal protective equipment, properly maintain the equipment they are operating, and use the safety features of the equipment. All welding equipment is safe to operate providing it is used in the proper manner. Malfunctioning welding equipment should be repaired by a trained service technician.

Confined Spaces

A confined space permit is necessary when repair welding is carried out in specific physical situations. A *confined space* is a workspace that has any of the following features: 1) it is large enough and so configured that a person can bodily enter it and perform assigned work, 2) it has limited or restricted means for entry or exit, or 3) it is not designed for continuous occupancy.

Examples of confined spaces include tanks, silos, storage bins, hoppers, vaults, pits, and trenches. Specific safety precautions required when working in a confined space include having a stand-by person available, guarding openings, using adequate ventilation, and performing oxygen content checks.

Welding and cutting operations performed in confined spaces create specific safety hazards. For instance, a leak in welding equipment can displace life-supporting oxygen levels. See Appendix. Some gases, such as argon, cannot be detected by smell and in confined or low-ventilated areas build to toxic levels. Welding, flame cutting, or allied processes should never be started until safety precautions are addressed. Welding safety procedures are developed to avoid hazards that might be present from welding operations. These include hazards of welding products, fumes and gases, electric shock, noise, heat, burns, and radiation. The welder must be satisfied that the confined space entry procedure and paperwork are satisfactory. If not, the welder has the right to refuse to perform the work until remedial actions are taken.

A permit is required when a confined space contains atmospheric hazards that have the potential to cause serious physical harm to a welder. See Appendix. A *permit-required confined space* is a confined space with one or more of the following characteristics:

- It contains or has the potential to contain a hazardous atmosphere.
- It contains a material that has the potential to engulf the entrant.
- It has an internal configuration such that the an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor that slopes downward and tapers to a smaller cross section.
- The confined space contains any other recognized serious safety or health hazard.

Confined space permits are issued for a specific period of time. Work must be completed in the alloted time or a new permit must be obtained.

When working in a confined space, have a stand-by person available to ensure a safe environment.

WARNING

Any welding equipment malfunctions shall be reported to the supervisor.

Under any or all of these conditions a permit system is required in which worker entry into the confined space is regulated. The employer must develop procedures for preparing and issuing permits to enter, work inside, and return the confined space to service at the end of the job. Permit-required confined spaces require assessment of entry procedures in compliance with OSHA standards prior to entry.

A *non-permit confined space* is a confined space that does not contain, or have the potential to contain, any hazards capable of causing death or serious physical harm. Conditions can change as tasks such as welding occur.

⚠ WARNING

Even with proper ventilation, a respirator should be used when metals that give off toxic fumes are welded.

Ventilation

Welding should only be performed in well-ventilated areas. There must be sufficient movement of air to prevent an accumulation of toxic fumes or, possibly, a deficiency of oxygen. All wind or air movement (ventilation) should be across the body, not from in front or from behind. Front- and rear-directed air movement causes wind tunnels (rolling) in front of the body and into the respiratory tract. Adequate ventilation becomes extremely critical in confined spaces where dangerous fumes, smoke, and dust are likely to collect. When working in a shop, the installed ventilation system is usually not adequate to vent the toxic fumes generated by welding. Additional ventilation is required, by the use of either a respirator, fans, or an exhaust system. See Figure 2-3.


Nederman, Inc.

Figure 2-3. *A ventilation system is required to remove toxic fumes, smoke, and dust caused by welding.*

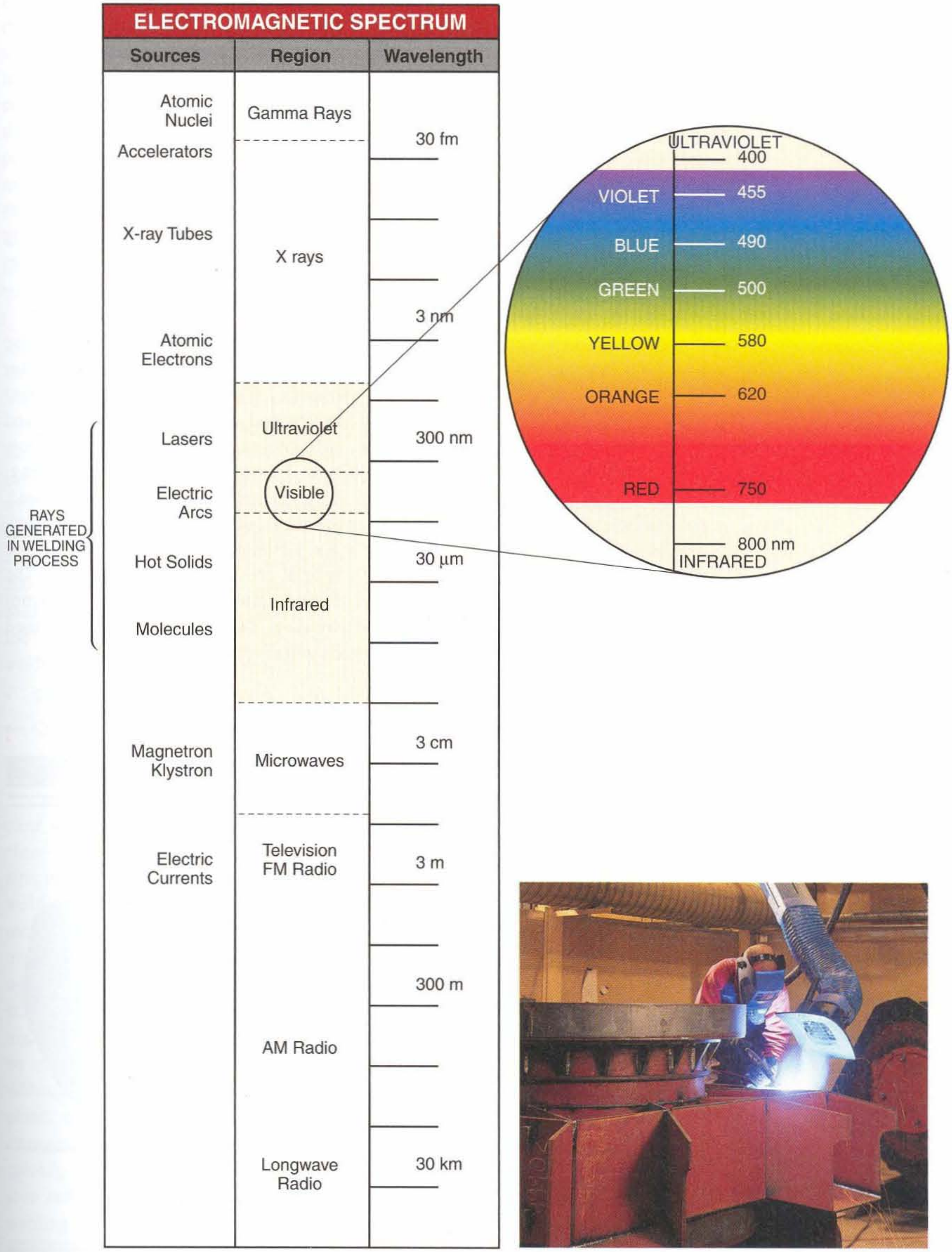
An exhaust system is necessary to keep toxic gases below the prescribed health limits in areas where much welding is performed. An adequate exhaust system is especially necessary when welding or cutting zinc, brass, bronze, lead, cadmium, or beryllium. This includes galvanized steel and metal painted with lead-based paint. Fumes from these materials are toxic and hazardous. Even when ventilation is provided, a respirator should be used when metals that give off toxic fumes are to be welded. Near the work area, toxic fumes may be breathed in before they can be extracted by the ventilation system. See Figure 2-4.


Sellstrom Manufacturing Co.

Figure 2-4. *A respirator should be worn when welding metals that produce toxic fumes.*

PERSONAL PROTECTIVE EQUIPMENT

Personal Protective Equipment is a device worn by welders to prevent injury. All personal protective equipment must meet requirements specified in OSHA 29 CFR and other applicable safety standards. All welding and cutting operations generate sparks and/or ultraviolet and infrared rays. Sparks may lead to serious burns, and ultraviolet and infrared rays are extremely dangerous to the eyes and skin. A welder must be aware of possible dangers to the body during any welding or cutting operation and learn the safe practices for personal welfare. Suitable eye protection, clothing, and ear protection are necessary. See Figure 2-5.



Nederman, Inc.

Figure 2-5. *The rays generated by welding are harmful to workers. A welder should always wear suitable personal protective equipment to protect against the ultraviolet and infrared rays generated during welding.*

When welding, always wear safety glasses with approved filter plates.

Eye Protection

Eye protection is essential for welders. Radiation produced by welding and cutting may be harmful to the welder. Radiant energy may be ionizing (such as X-rays) or non-ionizing (such as ultraviolet, visible, or infrared light). Radiation can burn the skin and damage the eyes. The effects depend on the radiant energy wavelength and intensity, and extent of exposure.

Most arc welding and torch cutting processes produce non-ionizing radiation such that eye protection is necessary. A welding arc should only be viewed through filter plates that meet the requirements of the American National Standards Institute (ANSI), Z87.1, *Practice for Occupational and Educational Eye and Face Protection.* Welders should always be alert for reflections from welding arcs. Passersby can be protected by welding screens, curtains, or remaining an adequate distance from the job.

Cutting and welding operations produce sparks and hot slag that can be projected from the welding surface toward the welder. Proper protection must be used to prevent injury to the eye. Eye protection is available with prescription lenses for welders who normally wear glasses. Some welders may prefer to have prescription lenses on the safety glasses because wearing glasses, safety glasses, and a helmet may be unwieldy.

Helmets. Welders also wear protective welding helmets with special filter plates or filter glasses to protect against injury and exposure to ultraviolet and infrared rays. Helmet designs allow both hands to be used for welding. Helmets are made to fit over the head, attach to hard hats, or be held by hand. An adjustable headband inside the helmet provides a comfortable fit. The helmet may be swung up when not welding. The hand-held helmet is used by observers. See Figure 2-6.

Welding Helmets
Figure 2-6

Figure 2-6. *A welding helmet protects the welder from infrared and ultraviolet rays and hot sparks.*

Welding helmets should be in good condition since openings or cracks can allow arc light through. A cover plate should be placed on the outside of the filter plate to protect it from weld spatter. The filter plate should be made of tempered glass so that it will not shatter if hit by flying objects. Filter plates are marked showing the manufacturer, the shade number, and the letter H indicating they have been treated for impact resistance.

Helmets may have fixed or adjustable lenses. Auto-darkening lenses darken in less than a hundred-millionth of a second when arc light strikes the filter.

Colored lenses should be examined and replaced if cracked. Lenses come in different shades, depending on the welding to be done. For oxyacetylene cutting operations, a #5 shade may be used. For arc welding at 75 A (amps) to 200 A, #10 shades or higher should be used. In general, for welding operations, the recommended shades, based on welding current, are as follows:

- Shade 10 — 75 A to 200 A
- Shade 12 — 200 A to 400 A
- Shade 14 — over 400 A

Colored lenses are protected by clear glass or plastic cover plates. The clear lens is placed over the colored lens inside the face plate. During the welding process, small particles of metal fly upward from the work and may lodge on the lens, distorting the welder's view. However, clear vision is necessary at all times during welding, so the clear plastic cover plate must be replaced when it becomes spattered. Although the methods of inserting cover plates differ among manufacturers, changes can be made easily and quickly. The cover plates are inexpensive and can be purchased from any welding supply dealer. Always follow manufacturer recommendation for the appropriate lenses and cover plates.

Safety Glasses and Goggles. A welding helmet does not provide total protection to a welder, so safety glasses and/or goggles should be worn at all times when welding. During shielded metal arc welding, a thin crust (slag) forms on the deposited bead. This slag must be removed from the weld. When removing the slag, tiny particles may be deflected upward. Because of stresses that build up in the weld, slag may occasionally pop off the weld. These particles can cause serious eye injury unless proper eye protection is worn. See Figure 2-7.

For most arc welding operations, a #10 shade should be used. For oxyacetylene cutting, a #5 shade can be used.

Safety Glasses and Goggles
Figure 2-7

SAFETY GLASSES

GOGGLES

Figure 2-7. *Safety glasses or goggles should always be worn during welding to prevent damage to the eyes resulting from deflected slag.*

⚠ WARNING

Never look at a welding arc without a welding helmet.

Proper Clothing

Welders are required to wear the proper protective clothing to shield them from burns resulting from sparks, spatter, and the harmful rays emitted by welding. Welders and workers in the area should wear protective clothing made of fire-resistant

material. Pant cuffs or clothing with open pockets that can catch and retain molten metal or sparks should not be worn. Work boots, leather leggings, and fire-resistant gloves should be worn. Pant legs should be worn over the outside of the boots. Helmets and hand shields that provide protection for the face, neck, and ears should be worn, as well as a protective head covering. Approved work clothes, a headcap, welding helmet, work boots, and gloves are required for all light-duty welding and cutting operations. In addition, heavy-duty welding requires a leather jacket or leather apron and leather gauntlet-type gloves.

In addition to approved work clothes, heavy-duty welding requires a leather jacket or apron and leather gauntlet-type gloves.

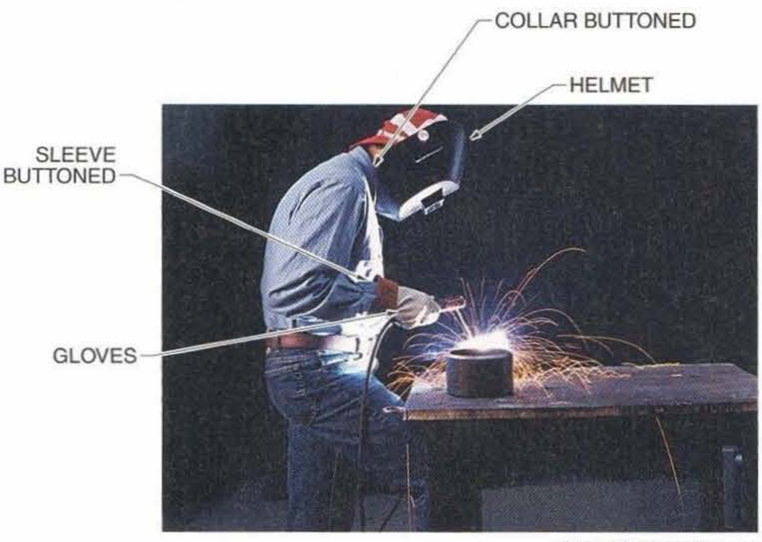
Work Clothing. Work clothes worn by welders should be made of natural materials such as leather, wool, or cotton as these materials have a higher resistance to burning. Synthetic materials such as polyester should never be worn, as they melt and burn easily, and can cause severe injury to a welder.

Coveralls or work clothes should be heavy enough to prevent infrared and ultraviolet rays from penetrating to the skin. Cuffs on pants should be turned down or eliminated and pockets removed to prevent molten metal from catching in the clothes. Sleeves and collars should be kept buttoned. See Figure 2-8.

Gloves. Gloves should be worn to protect the hands from ultraviolet rays and spattering hot metal. Gloves are also useful when picking up metals that have been welded. The red hot color of metal fades and metal returns to its original gray color quickly; however, metal remains hot for some time after welding and cannot be identified as hot simply by looking at it. Gloves should be worn at all times when working with metal that may be hot to prevent the hands from being burned.

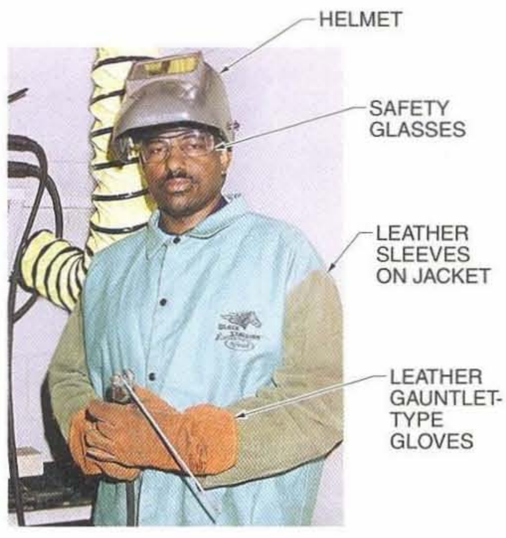
Several types of gloves are available for welding. Leather work gloves and gauntlet-type gloves both provide

Proper Clothing
Figure 2-8



The Lincoln Electric Company

LIGHT DUTY WELDING



HEAVY DUTY WELDING

Figure 2-8. *The proper protective clothing is required to prevent injury or burns during welding.*

protection. Gloves should be flexible enough to permit proper hand movement, yet not so thin as to allow the heat to penetrate easily. See Figure 2-9.

Leather Jackets and Aprons. A leather jacket or apron is recommended when welding, as spatter might cause injury. A leather apron offers the best protection from hot spatter. In situations where there may not be an excessive amount of metal spatter, suitable coveralls (fire-retardant) may be worn to protect the clothing.

Gloves
Figure 2-9

Smith Equipment

WORK

GAUNTLET-TYPE

Figure 2-9. *Always wear gloves when welding and cutting to protect the hands from ultraviolet rays and spatter.*

Work Boots. Work boots must be approved safety shoes or boots made of leather or other approved material, with a reinforced or steel toe to prevent impact injuries. Metatarsal (instep) protection should also be worn to prevent slag material or sparks from dropping into the shoes. Street shoes must never been worn, regardless of the material from which they are made.

Never place jackets or shirts over oxygen or gas cylinders. Gas can leak under clothing and start a fire.

Ear Protection

Some welding operations, such as chipping, peening, air carbon arc gouging, and plasma arc cutting, produce high levels of noise. Engine-driven generators can also be noisy. Excessive noise affects hearing capability. It may be a temporary loss from which the ears recover if removed from the noise source. However, if a person is exposed to this same noise for long periods of time, the hearing loss may become permanent. The time required to develop permanent hearing loss depends on various factors. Ear plugs or ear muffs must be used when engineering controls (such as shielding) are not effective in reducing excessive noise.

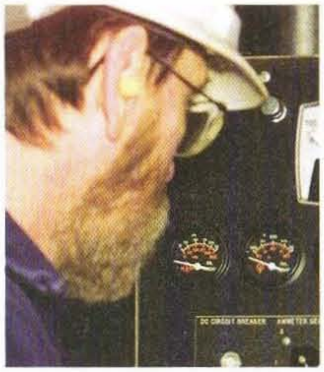
Ear protection should be worn when welding as the excessive noise generated by welding can affect hearing.

Ear plugs and ear muffs are supplied by the employer in situations where workers are exposed to extreme noise. *Earplugs* are a device inserted into the ear canal to reduce the level of noise reaching the eardrum. Earplugs are made of moldable rubber, foam, or plastic. *Ear muffs* are a device worn over the ears to reduce the level of noise reaching the eardrum. See Figure 2-10.

Safe noise levels and levels at which hearing protection is required are indicated by regulations developed by the Environmental Protection Agency (EPA) and OSHA. Ear protection devices are rated for noise reduction to maintain permissible noise levels. A *noise reduction rating number (NRR)* is a number that indicates the noise level reduction in decibels (dB).

Figure 2-10. *Ear protection should be used for welding operations, such as chipping, peening, carbon arc air gouging, and plasma arc cutting, that produce high levels of noise.*

Ear Protection
Figure 2-10



EAR PLUG

EAR MUFF

For example, an NRR of 27 means that the noise level is reduced by 27 dB when tested under factory conditions. If a factory has a noise level of 95 dB, the exposure limit without ear protection is 4 hr. For workers exposed to those noise levels for an 8 hr shift, ear protection is required. Ear plugs commonly have an NRR of about 27, which would reduce the noise level from 95 dB to 68 dB. Sixty-eight decibels is a moderate intensity and well within the permissible exposure limit for an 8 hr shift, thus reducing the danger of hearing impairment. See Figure 2-11.

HAZARDOUS SUBSTANCE CONTAINERS

Fumes and gases are produced by welding and cutting and some are harmful to a welder's health. Problems are compounded by welding or cutting on surfaces contaminated by chemicals or corrosion products. Fumes and solid particles originate from the welding process. Gases are generated during welding, or may be produced by the effects of welding radiation on the surrounding environment.

Adequate ventilation must be available to remove fumes from the work area. Where ventilation may be inadequate, air sampling should be used to determine where corrective measures are to be applied.

Hazardous substances include those that are combustible, toxic, or corrosive. Hazardous substances may be present in a container having previously held any of the following:

- a volatile liquid that releases potentially hazardous, flammable, and/or toxic vapors at atmospheric conditions
- an acid or alkaline material that reacts with metals to produce hydrogen
- a nonvolatile liquid or solid that at ordinary temperatures does not release potentially hazardous vapors, but does so if the container is heated
- a dust cloud of finely divided airborne particles that may still be present in an explosive concentration
- a flammable or toxic gas

Cleaning Hazardous Substance Containers

For maximum safety, only qualified personnel shall designate the container cleaning method. The cleaning method

Decibel Levels
Figure 2-11

SOUND LEVELS		
Intensity of Noise	**Decibels (dB)**	**Example**
Deafening	120 110	thunder, artillery, nearby riveter
	100	
Very Loud	90	loud street noise, noisy factory, unmuffled truck
	80	
Loud	70	noisy office, average street noise, average factory
	60	
Moderate	50	noisy home, average conversation, quiet radio
	40	
Faint	30	quiet home, private office, quiet conversation
	20	
Very Faint	10 0	whisper, sound proof room, threshold of audibility

NOISE LEVEL INTENSITY	
Duration per Day*	**Noise Level†**
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
¾	107
½	110
¼ or less	115

* in hrs
† in decibels (dB)

PERMISSIBLE EXPOSURE TIMES

NOISE REDUCTION RATING: ‡

Ear Plugs = 27 dB
Ear Muffs = 32 dB
‡ typical, varies by manufacturer

Example: A noisy factory has a decibel level of 95 dB that with ear plugs can be lowered to 68 dB, which is of moderate intensity but well within permissible exposure times.

Figure 2-11. *Ear protection reduces the decibel level to which the eardrums are exposed, reducing the chance of damage to the worker's hearing.*

used depends upon the substance previously held in the container. The water method of cleaning is used when the substance is known to be readily soluble in water. The residue can be removed by completely filling the container with water and draining several times. When the substance originally held in the container is not readily soluble in water, additional methods of cleaning the container are available, including the hot chemical solution, steam, mechanical cleaning, or chemical cleaning methods. Occasionally, combinations of all methods of cleaning must be used prior to welding or cutting. Care must be taken to protect personnel and to prevent hazardous reactions when combining cleaning methods.

⚠ WARNING

A container that has held unknown substances should never be cleaned and welded because unknown safety hazards are involved.

Hot Chemical Solution Method. The hot chemical solution method uses trisodium phosphate (a strong washing powder) or a commercial caustic cleaning compound dissolved in hot water. The cleaning agents are mixed with hot water and added to the container to be cleaned. The container is then filled with water and stirred until the chemicals have been cleaned from the container.

Steam Method. The steam method for cleaning containers uses low-pressure steam and a hot soda or soda ash to remove substances. The cleaning agents are added to the container and the container is filled with live steam and stirred until the chemicals have been removed from the container.

Mechanical Cleaning Method. The mechanical cleaning method is generally used when scaly, dry, or insoluble residues have been left on the surface of the container. Mechanical cleaning may be performed by scraping, sand or grit blasting, high-pressure water washing, brushing, filling the container one-quarter full of clean dry sand and rolling it on the floor, or any method in which the contaminant can safely be dislodged. During mechanical cleaning, the container should be grounded to minimize the possibility of static charge buildup and spark charges.

Chemical Cleaning Method. The chemical cleaning method is generally used when the container has insoluble deposits or when it cannot be mechanically cleaned. Care must be used in selecting a chemical solvent; some solvents may be as hazardous as the deposits they are intended to remove. When selecting chemical solvents, consult the manufacturer of the material to be removed.

Containers should be checked carefully after any cleaning method to ensure that all chemicals have been thoroughly removed from the container.

As a final precaution after cleaning, a container should be vented and filled with water before welding or cutting. The container should be arranged so that the container can be kept filled to within a few inches of the point where the welding or cutting is to take place, but not interfere with welding. See Figure 2-12. When welding or cutting on containers, observe the following safety precautions:

- Vent the container to allow for the release of air pressure or steam during welding.
- Use a spark-resistive tool to remove heavy sludge or scale when scraping or hammering.
- Never use oxygen to ventilate a container as it may start a fire or cause an explosion.

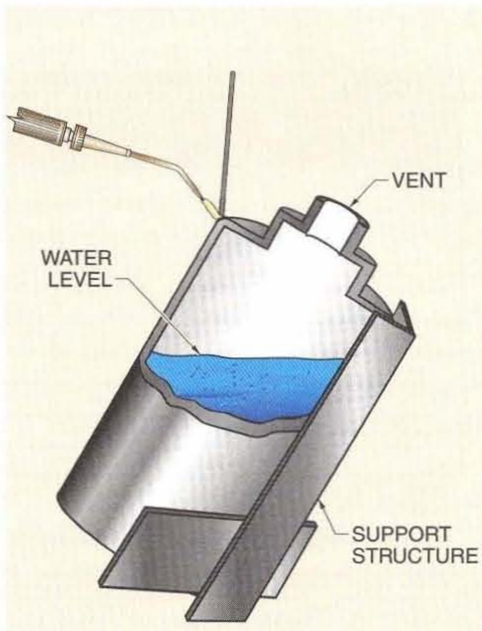


Figure 2-12. *Containers should be partially filled with water before cutting or welding.*

- Never rely on sight or smell to determine the safety of welding or cutting a closed container. A small amount of residual flammable liquid or gas may not be detectable, but it could cause an explosion.
- Never weld or cut drums, barrels, or tanks until the danger of fire or explosion has been eliminated.

Material Safety Data Sheets

Before any container is cleaned, the hazardous characteristics of the substance previously held by the container must be determined. Information about the substance and safety precautions to follow when working with the substance are contained in a Material Safety Data Sheet (MSDS). A *Material Safety Data Sheet (MSDS)* is printed material that includes data about every hazardous component comprising 1% or more of a material's content and is used by a manufacturer, importer, or distributor to relay chemical hazard information to the employee.

MSDSs are obtained from the suppliers of welding filler metals, fluxes, and gases. They should be kept on file at a designated location in the workplace. The information is used to inform and train employees on the safe use of hazardous materials. See Figure 2-13.

Material safety data sheets include data about every hazardous component comprising 1% or more of a material's content.

If an MSDS is not provided, the employer must write to the manufacturer, distributor, or importer to obtain the missing MSDS. An MSDS has no prescribed format but must contain certain information related to the chemical hazard, identification, physical and chemical characteristics, fire hazards, reactivity and health hazard data, handling precautions,

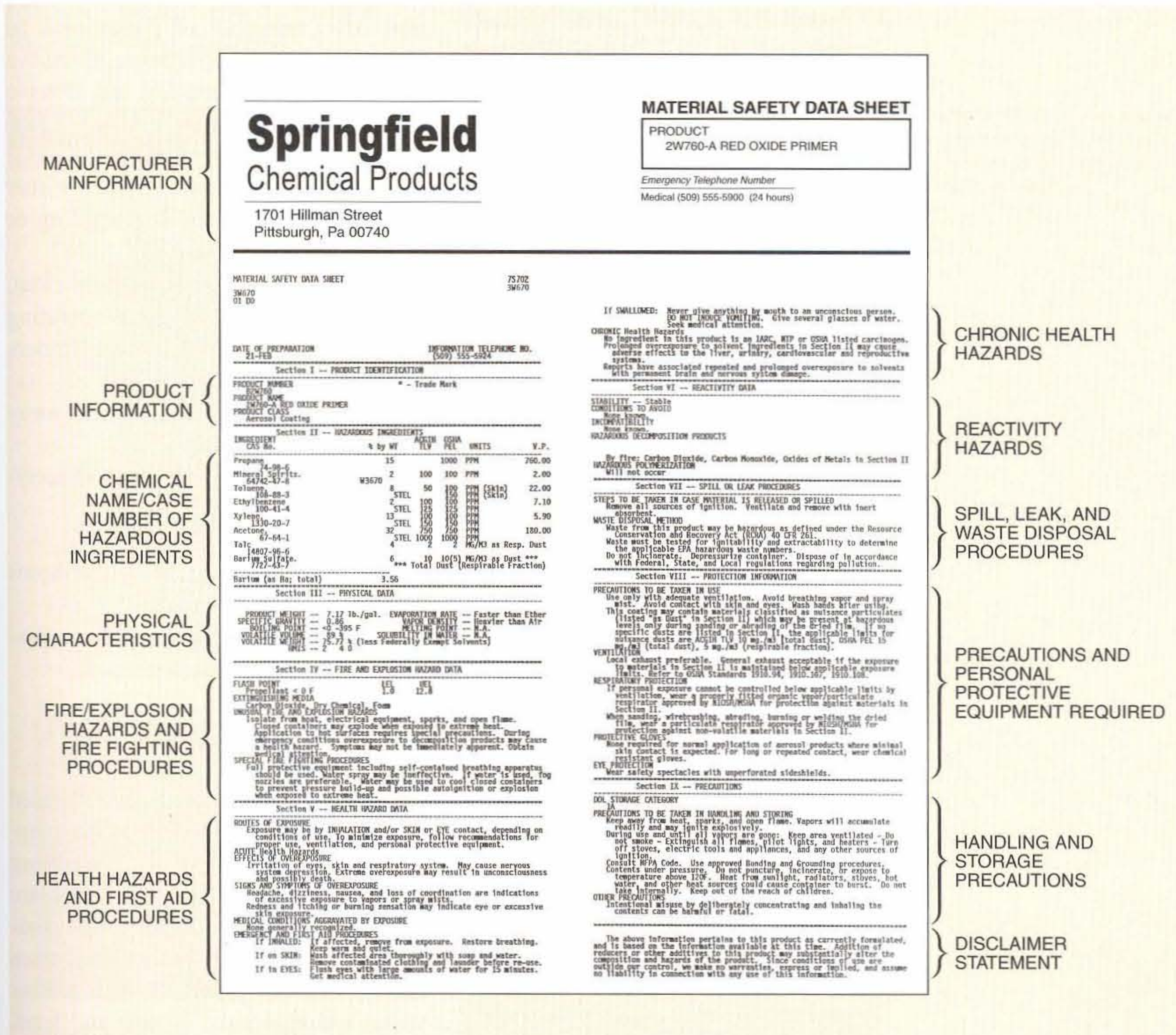


Figure 2-13. *An MSDS is provided with all chemical containers used in industry. Before welding such containers, the MSDS must be checked to ensure that chemicals have been properly removed from the container.*

and control measures of the hazardous material. MSDS files must be kept up-to-date and well organized to allow quick access to information in an emergency situation. Employees should become familiar with the MSDS for chemicals commonly encountered on the job.

CUTTING SAFETY

Fires often occur during cutting operations because proper safety precautions were not followed. Sparks and falling slag can travel great distances and can pass through cracks in walls or floors out of sight. Persons responsible for performing or supervising cutting should observe the following safety precautions:

- Never use a cutting torch where sparks will be a hazard, such as near rooms containing flammable materials, especially dipping or spraying rooms.
- Sweep floors clean and wet them before beginning cutting. Provide a bucket or pan containing water or sand to catch dripping slag.
- Use fire-resistant guards, partitions, or screens if cutting must be performed near flammable materials that cannot be moved.
- In greasy, dirty, or gaseous atmospheres, extra precautions should be taken to prevent explosions that can result from electric sparks or open fires during cutting or welding operations.
- Keep flame and sparks away from oxygen cylinders and hoses.
- Keep combustible materials at least 35′ away from any cutting or welding operations.
- Never cut near ventilators.
- Never use oxygen to dust off clothing or workpieces.
- Never use oxygen as a substitute for compressed air.

Welders are frequently exposed to hazardous situations. Personal protective equipment such as safety shoes, goggles, helmets with protective lenses, and other devices to prevent injury should always be used.

OXYACETYLENE WELDING SAFETY

Safety precautions for oxyacetylene welding cover the proper handling of cylinders, operation of the regulators, use of oxygen and acetylene, care of welding hoses, testing for leaks, and lighting a torch. All safety regulations should be followed.

Additionally, all piping and fittings used to convey gases from a central supply system to work stations must withstand a minimum pressure of 150 psi. Oxygen piping may be black steel, brass, or copper. Only oil-free compounds should be used on oxygen threaded connections.

Piping for acetylene must be wrought iron. After assembly, all piping must be blown out with air or nitrogen to remove foreign materials before first use. Observe the following basic rules for the safe handling of oxyacetylene equipment:

- Locate the nearest fire extinguisher before performing any welding or cutting operation.
- Keep oxyacetylene equipment clean, free of oil, and in good operating condition. Never handle cylinders with oily or greasy gloves.
- Keep heat, flame, and sparks away from combustibles.
- Prevent leaks in oxygen and acetylene cylinders.
- Open cylinder valves slowly.
- Purge oxygen and acetylene hoses before lighting torch.
- Never move cylinders without protective caps in place.

ARC WELDING SAFETY

Arc welding processes include shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), and flux cored arc welding (FCAW). General safety measures are indicated for these areas since arc welding equipment for each process varies considerably in size and type. Equipment may range from a small portable SMAW machine to a highly

mechanized production spot welding machine. Manufacturer recommendations should be followed for the equipment used. See Figure 2-14.

Electric shock can be fatal. Live electrical parts should not be touched, and manufacturer instructions and all recommended safety practices must be followed. Faulty insulation, improper grounding, and incorrect operation and maintenance of electrical equipment are typical sources of danger from electric shock. Use only welding machines that meet recognized national standards, such as those identified by the National Electrical Manufacturers Association (NEMA), NEMA EW-1, *Electric Arc Welding Power Sources.*

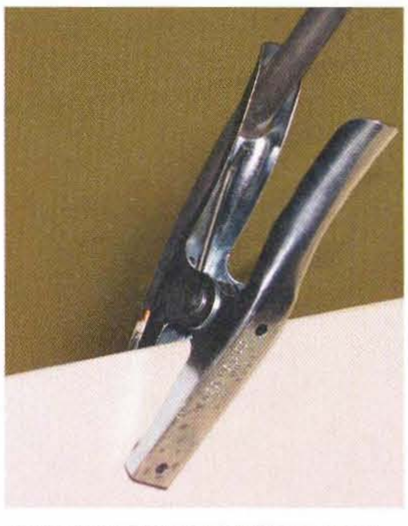
Thermadyne Industries, Inc.

Proper workpiece connections to complete a welding circuit prevent electric shock and personal injury.

Common Welding Safety Practices

Figure 2-14

LOCATE POWER DISCONNECT NEAR WELDING MACHINE



ATTACH WORKPIECE CONNECTIONS SECURELY

DO NOT PICK UP HOT WORKPIECES

The Lincoln Electric Company

USE OPERATING CURRENT LEVELS WITHIN RATED CAPACITIES

Figure 2-14. *Following common safety precautions reduces the chances of an accident occurring during welding.*

Always use insulated electrode holders when welding with SMAW to prevent electric shock and injury.

All electrical equipment and the workpiece should be grounded. The workpiece lead must not be used as a ground and is used only to complete the welding circuit. The correct size leads for the welding application should be used. Sustained overloading causes failure of the welding leads and results in electric shock or fire hazard. All electrical connections should be tight, clean, dry, and in good condition. Poor connections can overheat and melt, or produce dangerous arcs and sparks. Water, grease, or dirt must not be allowed to accumulate on plugs, sockets, or electrical units.

Only insulated electrode holders should be used for SMAW. Semiautomatic welding guns for continuous wire processes should use low-voltage control switches so that high voltage is not brought into the electrode holder in the welder's hands. In fully automatic equipment, higher voltages are permitted because they are inaccessible to the operator during the normal welding sequence.


Welders who follow all safety requirements ensure a safer work environment for themselves and others in the work area.

High open circuit voltages should be avoided. When several welders are working with arcs of different polarity, or when a number of AC machines are being used, the open circuit voltages can be additive and increase the severity of the shock hazard.

Electrode leads and workpiece leads should not be coiled around welding machines or the welder. Electrode holders should not be hung where they can accidentally come into contact with the other side of the circuit. Electrodes should be removed from the electrode holder when not in use. Power cables coming into a welding machine should not come into contact with welding leads. The welding machine must be kept dry and if it should become wet it must be dried properly by electrical maintenance personnel. In addition, the work area must be kept dry. Welders should never work in water or damp areas because water reduces a welder's resistance and increases potential electrical hazards. The welder should stand on a board or insulated platform. The following safety rules are common to most arc welding operations:

- Install welding equipment according to provisions of the National Electrical Code®.
- Use welding machines equipped with a power disconnect switch located at or near the machine so the power can be shut off quickly.
- Ensure that the work area is grounded. Do not ground to pipelines carrying gases or flammable liquids.
- Use proper safety guards when using press-type welding machines.
- Use suitable spark shields around equipment when flash welding.
- Turn OFF the welding machine, pull the power disconnect switch, remove the electrode, and hang the electrode holder in its designated place when welding is completed.

- Inspect welding cables for cuts, nicks, or abrasions.
- Do not pick up pieces of metal that have just been welded or heated.
- Do not make repairs to welding equipment unless power to the machine is OFF. The high voltage of arc welding machines can cause severe, even fatal injuries.
- Do not change polarity when the machine is under load. The machine should be idled and the circuit open; otherwise, an arc may occur, burning the contact surface of the switch and severely burning the welder.
- Do not overload welding leads or operate a machine with poor connections. Operating with currents beyond the rated cable capacity causes overheating.
- Neatly arrange the welding leads and secure the proper connections.
- Do not weld on hollow (cored) castings unless they have been properly vented; an explosion may occur.

PREVENTING FIRES

Welding operations expose welders to heat, sparks, and flame. Precautions should be taken to ensure that the job site is safe and that adequate fire prevention strategies are in place.

Fire may be produced by molten metal, sparks, slag, and hot work surfaces. Sparks may cause fire or explosion if precautionary measures are not used. Sparks can pass through or become lodged in cracks, clothing, pipe holes, and other small openings in floors and partitions. Typical indoor combustible materials are floors, partitions, roofs, and building contents. Indoor combustible materials may consist of wood, paper, clothing, plastics, and chemical and flammable liquids and gases. Examples of outside combustible materials are dry leaves, grass, and brush.

Combustible materials should be removed from the work area, or the location of the work must be at least 35′ away from combustible materials. If neither is possible, combustibles should be protected with a cover of fire-resistant materials. A fire extinguisher should be kept near cutting and welding operations at all times. If the risk of fire is great, fire watchers should be available. If possible, the work area should be enclosed with portable, fire-resistant screens. Welding or cutting should not be done where dangerously reactive or flammable gases are present.

Explosion, fire, or other health hazards may result if welding or cutting is performed on containers that are not free of hazardous substances. No container should be presumed to be clean or safe. Containers can be made safe for welding and cutting provided the necessary steps and safety precautions are followed.

⚠ CAUTION

Combustible materials must be located at least 35′ away from any area where welding is to be done.

Miller Electric Manufacturing Company

Welding shops should be equipped with a fire extinguisher that is located near the work area for easy access in case of fire.

FIRE EXTINGUISHER CLASSES		
Class	**Combustible Material (and Graphic Representation)**	**Extinguishing Chemicals**
A	 • Wood • Paper • Rubber • Plastic • Cloth	• Water • Dry chemicals
B	 • Flammable liquids • Grease • Gases	• Dry chemicals • Foam • Carbon dioxide
C	 • Electrical	Non-conducting agent such as: • Dry chemicals • Carbon dioxide
D	 • Combustible metals • Magnesium • Titanium • Zirconium • Sodium	• Extinguisher particular to type of metal
K	 • Commercial cooking grease	• Wet chemicals • Dry chemicals

Figure 2-15. *Fire extinguishers are classified as A, B, C, D, and K.*

The National Fire Protection Association (NFPA) classifies fires into five types: A, B, C, D, and K. The classifications are based on the combustible material and the type of extinguisher required to put out the fire. Extinguisher classifications can also be identified by color and shape. See Figure 2-15.

Class A

A Class A fire may be caused by most combustible materials, such as wood, paper, rubber, plastic, and cloth. Class A fires are the most common type of fire. A Class A fire extinguisher is identified by the color green inside a triangle shape. Class A fires can be extinguished with water or dry chemicals. Carbon dioxide, sodium, and potassium bicarbonate chemicals should not be used on a Class A fire.

Class B

A Class B fire is caused by flammable liquids, gases, or grease. A Class B fire extinguisher is identified by the color red inside a square. Class B fires can be extinguished with dry chemicals. Foam and carbon dioxide extinguishers may also be used.

Class C

A Class C fire is an electrical fire. A Class C fire extinguisher is identified by the color blue inside a circle. Electrical fires require a non-conducting agent, such as carbon dioxide or dry chemicals, to extinguish them. Foam extinguishers or water should never be used on an electrical fire.

Class D

A Class D fire is caused by combustible metals, such as magnesium, titanium, or sodium. A Class D fire extinguisher is identified by the color yellow inside a star. Class D fires cannot be extinguished with a common A, B, or C extinguisher; the chemicals in common

extinguishers can intensify the fire, rather than put it out. Dry powder extinguishers are available that are made specifically for metal hazards.

Class K

A class K fire is caused by grease in commercial cooking equipment. Class K fire extinguishers coat the fire with wet or dry chemicals.

Common dry chemical extinguishers should be available in case sparks from welding set other materials on fire. The two basic types of dry chemical extinguishers are the stored-pressure and the cartridge operated. A fire extinguisher labeled ABC is composed of dry chemicals and is capable of extinguishing class A, B, and C fires. A fire extinguisher labeled either A, B, or C can only extinguish the fire for which it is labeled. Using an improper fire extinguisher can have an adverse effect on a fire, making the fire worse rather than extinguishing it.

Welders must be particularly aware of the fire hazards involved in the metals they are welding and ensure that the proper type(s) of extinguisher are available.

POINTS TO REMEMBER

1. Weekly safety meetings are a convenient way for employers to discuss relevant job site safety issues and concerns.
2. When working in a confined space, have a stand-by person available to ensure a safe environment.
3. When welding, always wear safety glasses with approved filter plates.
4. For most arc welding operations, a #10 shade should be used. For oxyacetylene cutting, a #5 shade can be used.
5. In addition to approved work clothes, heavy-duty welding requires a leather jacket or apron and leather gauntlet-type gloves.
6. Never place jackets or shirts over oxygen or gas cylinders. Gas can leak under clothing and start a fire.
7. Ear protection should be worn when welding as the excessive noise generated by welding can affect hearing.
8. Material safety data sheets include data about every hazardous component comprising 1% or more of a material's content.
9. Always use insulated electrode holders when welding with SMAW to prevent electric shock and injury.

QUESTIONS FOR STUDY AND DISCUSSION

1. What are some of the main causes of accidents?
2. Why should all accidents be reported immediately?
3. How is it possible to become involved in an accident when playing around in the shop?
4. What may happen if welding equipment is used without proper instruction?
5. What should be done if a malfunction occurs in any welding equipment?
6. What general practice should be followed regarding ventilation when performing welding?
7. Why should used containers be thoroughly cleaned and safety processed before any welding or cutting is done?
8. Why do fires often occur during a cutting operation?
9. What are some precautions that should be taken when using a cutting torch?
10. Why must welders wear proper personal protective equipment when welding?
11. A dry chemical fire extinguisher can be used to extinguish which class(es) of fire?
12. What class of fire extinguisher should be used for a fire involving burning metal?
13. What is the purpose of an MSDS?
14. Why should a welder never look at an electric arc without eye protection?
15. What determines the correct shade of lens for use during welding?
16. Why should shaded lenses be covered with clear plastic lenses?
17. Why are safety glasses required when welding?
18. Why should leather gloves be worn when welding?

3 Joint Design & Welding Terms

Engineers and designers consider all factors in the design of a weld joint to ensure safety and efficiency. These factors include load requirements of the weld; the adaptability of the joint for the product being designed or welded; the accessibility of the weld; the type of load on the weld; the intended function of the structure; governing codes and specifications; and economic considerations such as the cost of preparing the joint.

Welded joints are used in virtually every industry. In the building industry, welds are used to join structural elements such as columns, trusses, girders, and other structural components.

WELDING TERMINOLOGY

Before proceeding with any welding operation, welders must understand common welding terms.

The *base metal* is the metal or alloy that is to be welded. An *electrode* is a component of the welding circuit that conducts electrical current to the weld area. Electrodes may be consumable or nonconsumable, depending on the welding process. Some electrodes, such as those used in shielded metal arc welding, are covered with a flux coating.

A *weld bead* is a weld that results from a weld pass. A *weld pass* is a single progression of welding along a weld joint. See Figure 3-1. A single pass weld requires only one weld pass. When laying a bead in a multiple-pass weld, each weld pass builds on the previous pass. The movement of the heat source

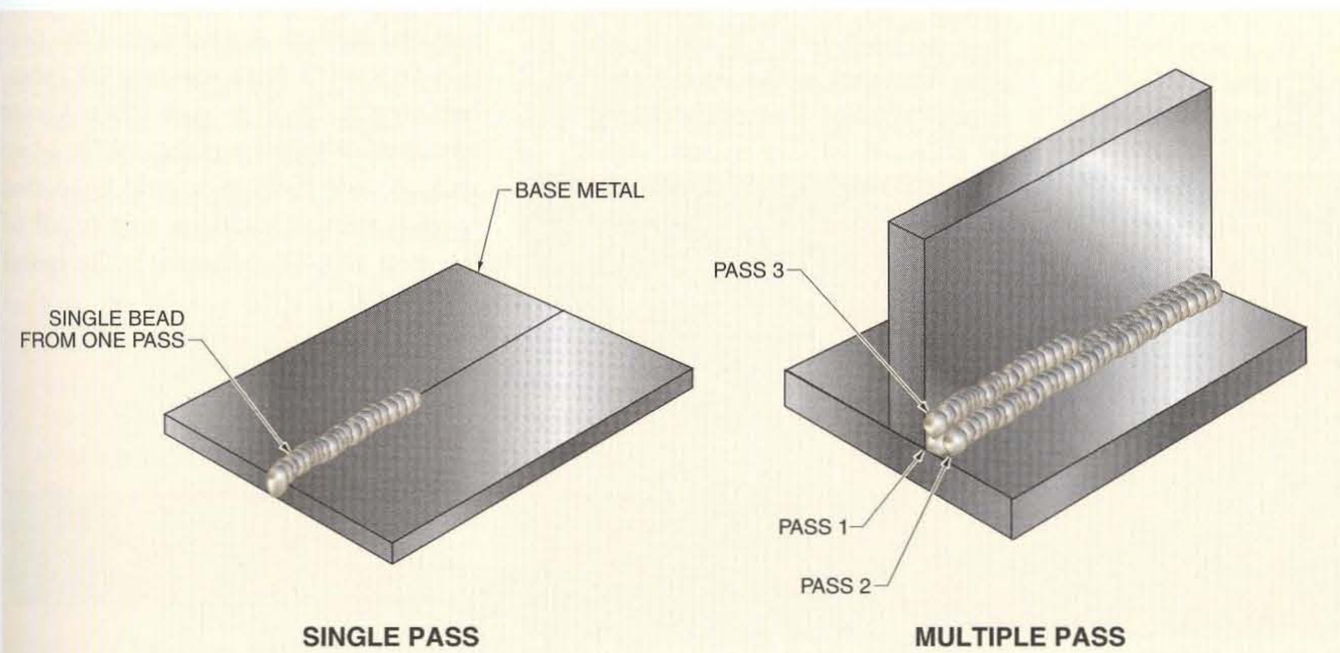


Figure 3-1. *When laying a bead, each pass builds on the previous pass. The movement of the welding heat source creates ripples as the bead is deposited.*

creates ripples as the weld bead is deposited. A *ripple* is the shape within the deposited bead caused by the movement of the welding heat source.

A *crater* is a depression in the base metal that is made by the welding heat source at the termination of the weld bead. *Joint penetration* is the depth of the weld metal from the weld face into the joint. The joint penetration measurement does not include the weld reinforcement measurement. See Figure 3-2.

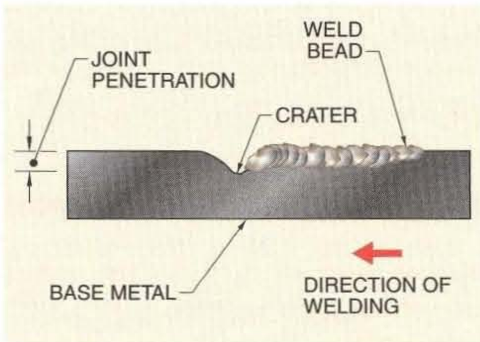


Figure 3-2. *A crater is a depression made in the base metal by the welding heat source. Joint penetration is the depth of the crater within the base metal.*

Weld reinforcement is the amount of weld metal in excess of that required to fill the joint. *Root reinforcement* is reinforcement on the side opposite the one on which welding took place. *Face reinforcement* is reinforcement on the same side as the welding.

The *root face* is the portion of the groove face within the joint root. The *root opening* is the distance between joint members at the root of the weld before welding. The root opening must be accurate so that excess welding is not necessary. *Weld width* is the distance from toe to toe across the face of the weld. See Figure 3-3.

The root pass is the initial weld pass that provides complete penetration through the thickness of the joint member.

The *weld toe* is the point where the weld metal meets the intersection of the base metal and the weld face. The toes are the points where the base metal and weld metal meet. The *weld face* is the exposed surface of the weld, bounded by the weld toes on the side on which welding was done. The face may be either concave or convex. The *weld root* is the area where filler metal intersects the base metal and extends the furthest into the weld joint.

The *actual throat* is the shortest distance from the face of a fillet weld to the weld root after welding. The *effective throat* is the minimum distance, minus convexity, between the weld face and the weld root. A *weld leg* is the distance from the joint root to the weld toe. The weld leg is the size of a fillet weld made in lap or T-joints. See Figure 3-4.

Filler metal is metal deposited in a welded, brazed, or soldered joint during the welding process. *Fusion welding* is welding that uses fusion of the base metal or base metal and filler metal to make a weld. Fusion welding is the most common method of joining metals.

Welding progression concerns the addition of filler metal in a weld joint root and beyond. A *joint root* is the portion of a weld joint where joint members are the closest to each other. A joint root may be either a point, a line, or an area. A *root bead* is a weld bead that extends into or includes part or all of the joint root. A *root pass* is the initial

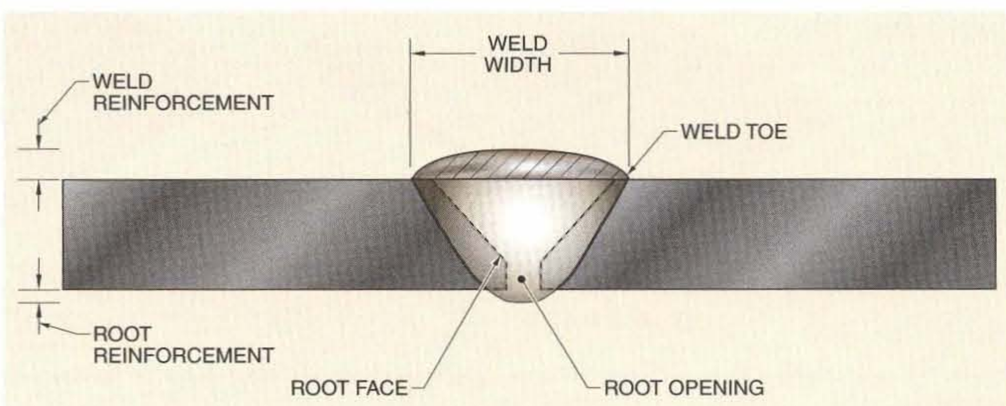


Figure 3-3. *A proper root opening must be prepared to prevent excess welding. Weld reinforcement is weld metal that is mounded across the weld width.*

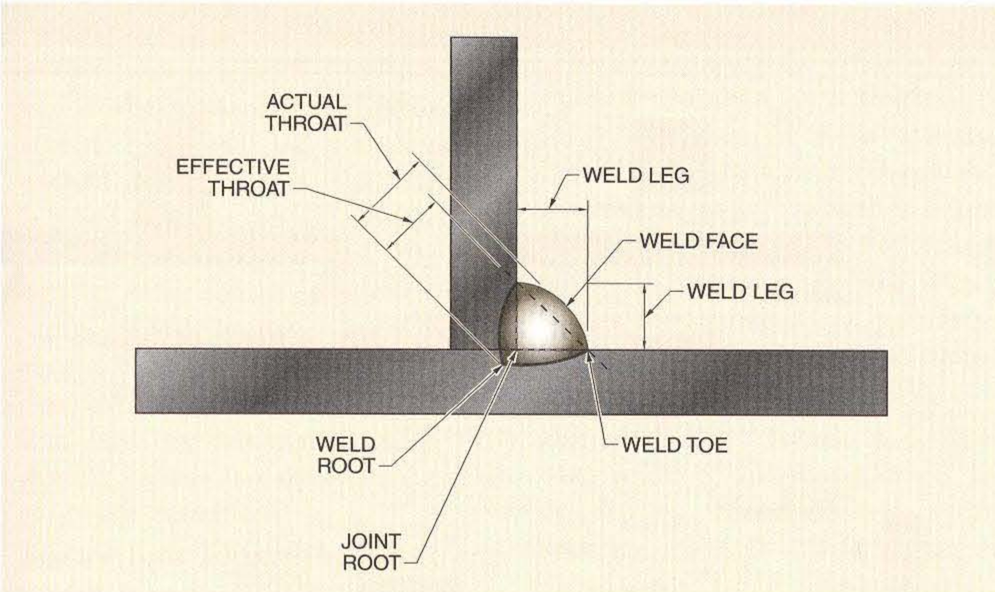


Figure 3-4. *A fillet weld can be cross-sectioned to identify its various parts.*

weld pass that provides complete penetration through the thickness of the joint member.

Several weld beads (multiple-pass weld) may be required to complete a weld. A multiple-pass weld contains two or more weld beads.

WELD JOINTS

A *weld joint* is the physical configuration at the juncture of the workpieces to be welded. Weld joints must be correctly designed and have adequate root openings to support the loads transferred from one workpiece to another through the welds. See Figure 3-5. The following are some basic considerations in the selection of any weld joint:

- whether the load will encounter tension, compression, bending, fatigue, or impact stresses
- how the load is to be applied to the joint, i.e., whether the load is a static, impact, cyclic, or variable load
- the displacement of the load in relation to the joint
- the direction from which the load is to be applied to the joint
- the cost of preparing the joint

Weld joint design is based on the strength of the joint, safety requirements, and the service conditions under which the joint must perform. Additionally, how stresses are to be applied during service, and whether tension, bending, or torsion is a factor, must be considered in joint design. Joint design requirements vary depending on whether the load is static, cyclic, or variable. Joints are also designed for economy or accessibility during construction and inspection. The five basic weld joints used are the butt, T, lap, corner, and edge joints. See Figure 3-6.

When designing weld joints for buildings, consideration must be given to the effects of transverse shrinkage, which occurs in support columns as a building is constructed. Shrinkage can accumulate if unaccounted for in the weld designs.

The Lincoln Electric Company

Professional welders must have an understanding of welding terminology, processes, and specifications.

Load Considerations
Figure 3-5

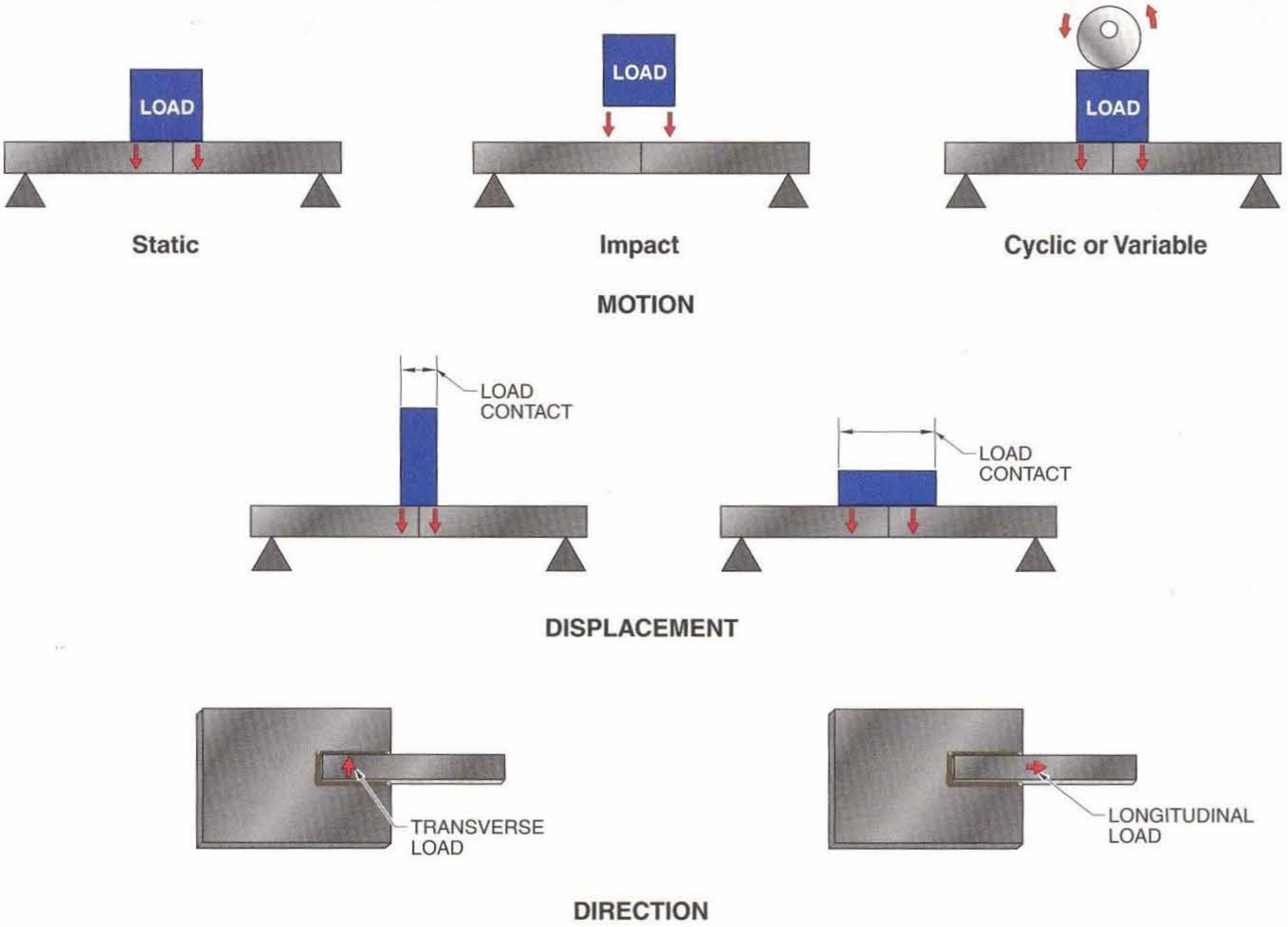
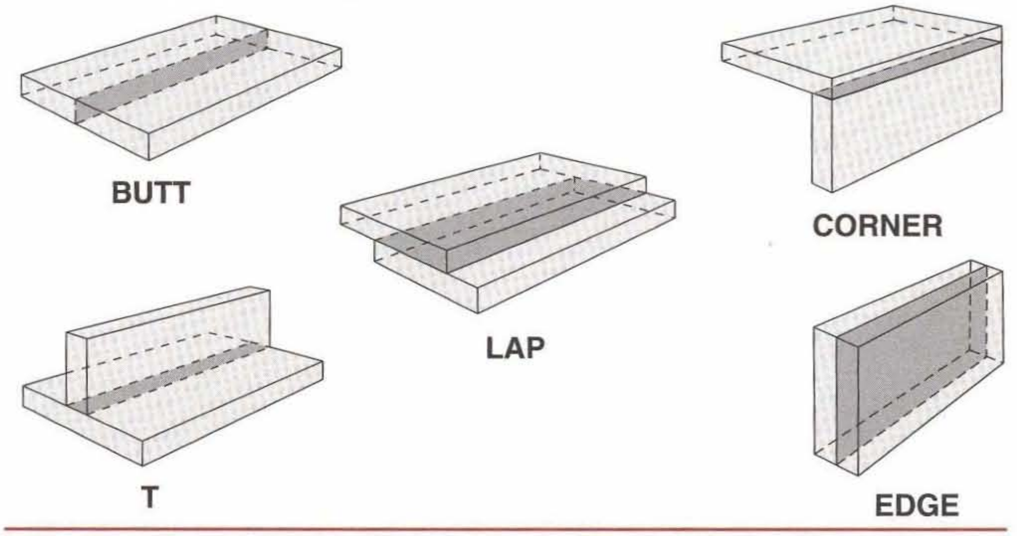


Figure 3-5. *Welders should be familiar with how loads will impact welded joints and with the requirements for making the proper joint selection.*

Figure 3-6. *The five basic weld joints used in welding are the butt, T, lap, corner, and edge.*

Basic Weld Joints
Figure 3-6



Butt Joints

A *butt joint* is a weld joint in which two workpieces are set approximately level to each other and are positioned edge-to-edge. In a butt joint, the weld is made between the edge surfaces of the two sections to be fused. The joint may be either square or grooved. Butt joints include square, single bevel, single-V, double-V, single-U, and double-U butt joints. See Figure 3-7. Butt joints are commonly used in fabricating vessels and subassemblies and for repair operations.

Square Butt Joints. The square butt joint is intended primarily for materials that are 3/16" thick or less. Square butt joints require full and complete fusion for optimum strength. For submerged arc welding, materials up to 3/8" thick with a minimum gap of 1/8" can be welded. The square butt joint is reasonably strong in static tension but is not recommended when the joint is to be subjected to fatigue or impact loads, especially at low temperatures. Preparation for a square butt joint requires matching only the edges of the workpieces. Square butt joints are an inexpensive weld joint option.

Single Bevel Butt Joints. A single bevel butt joint is a partial penetrating single bevel groove weld. It is welded from one side and is generally used on metals no more than 1/2" thick.

Single-V Butt Joints. A single-V butt joint is used on metal from 3/8" to 3/4" thick. Preparation for a single-V butt joint is costly because a special beveling operation and more filler material are required than for a square butt joint. A single-V butt joint is strong in static loading but, like the square butt joint, is not particularly suitable when subject to fatigue or impact loads at the weld root.

Double-V Butt Joints. A double-V butt joint is suitable for all load conditions. The double-V is often specified for stock that is heavier than metal used for a single-V. Heavy metals that use a double-V joint are typically 3/4" thick or greater. For maximum weld strength, penetration must be complete on both sides.

Square butt joints should be used with materials 3/16" thick or less.

The cost of preparing a double-V joint is higher than the single-V, but usually less filler material is required because a narrower groove angle can be used. To keep the joint symmetrical and warpage of the joint to a minimum, the weld bead must be alternated. The welding should be done first on one side and then the other, with the welder alternating sides until the groove is filled.

A double-V butt joint is suitable for all load conditions.

Single-U Butt Joints. A single-U butt joint meets all ordinary load conditions and is used for work requiring high-quality welds. The single-U works well on applications joining workpieces 1/2"

Butt Joints
Figure 3-7

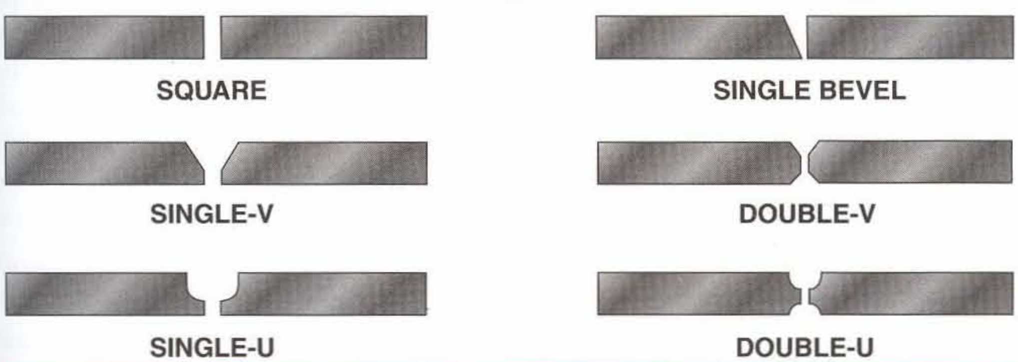


Figure 3-7. *Common butt joints used for welding include the square, single bevel, single-V, double-V, single-U, and double-U.*

to ¾″ thick. The single-U joint needs less filler metal than the single-V or double-V joint, and generally, less warpage occurs.

Double-U Butt Joints. A double-U butt joint is intended for heavy metals ¾″ thick or more on which welding can easily be accomplished on both sides. The double-U joint can meet all regular load conditions. Preparation costs are higher than for the single-U butt joint.

A T-joint is formed when two members are positioned approximately 90° to one another.

T-Joints

A *T-joint* is a weld joint formed when two workpieces are positioned at approximately 90° to one another in the form of a T. A T-joint can be made on all standard metal thicknesses. The edge of one workpiece rests on the surface of the base workpiece. Basic T-joints are square, single bevel, double bevel, single-J, and double-J. See Figure 3-8.

Square T-Joints. A square T-joint can be welded on one or both sides and requires the use of a fillet weld. Square T-joints can be used for thin or reasonably thick materials where applied loads subject the weld to longitudinal shear. Since the stress distribution of the joint may not be uniform, this factor should be considered where severe impact or heavy transverse loads are encountered. For maximum strength, considerable weld metal is required.

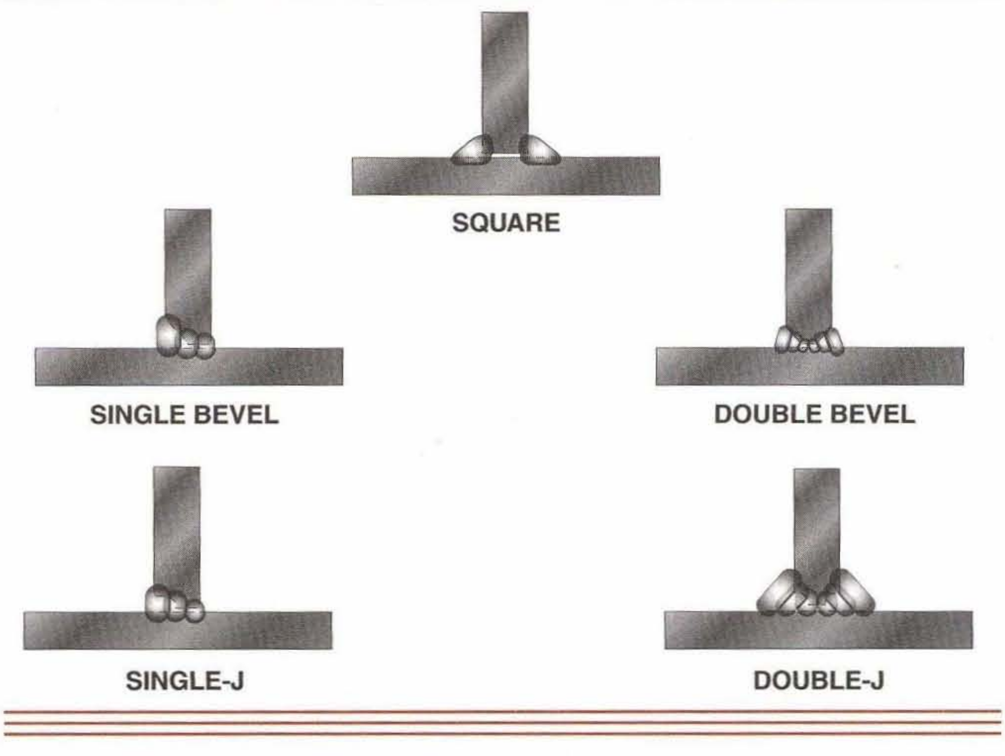
Single Bevel T-Joints. A single bevel T-joint can withstand a more severe load than the square T-joint since it allows for better distribution of stresses. It is generally confined to plates ½″ thick or less where welding can only be done from one side.

Double Bevel T-Joints. A double bevel T-joint is intended for use where heavy loads are applied in both longitudinal and transverse directions, and where welding can be done on both sides.

Single-J T-Joints. A single-J T-joint is used on plates 1″ thick or more where welding is limited to one side. It is especially suitable for welding workpieces that are exposed to severe loads.

Figure 3-8. *T-joints are used on all standard metal thicknesses and include square, single bevel, double bevel, single-J, and double-J.*

T-Joints
Figure 3-8



Double-J T-Joints. A double-J T-joint is particularly suitable for heavy plates 1½″ thick or more where unusually severe loads are encountered. Joint location should permit welding on both sides.

Lap Joints

A *lap joint* is a weld joint between two overlapping members in parallel planes. A lap joint is one of the strongest joints available, despite the lower unit strength of the filler metal. Lap joints are commonly welded on both sides. An overlap greater than three times the thickness of the thinnest workpiece is recommended. Two basic lap joints are single fillet and double fillet lap joints. See Figure 3-9.

Lap Joints
Figure 3-9

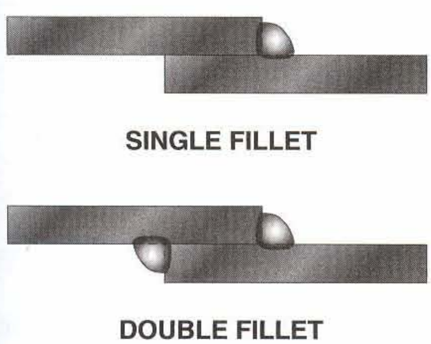


Figure 3-9. *The single fillet and double fillet lap joints are the strongest weld joints available.*

Single Fillet Lap Joints. A single fillet lap joint is very easy to weld. Filler metal is deposited along the seam on one side of the joint. The strength of the single fillet weld depends on the size of the fillet. Metal up to ½″ thick can be welded with a single fillet if the loading is not too severe.

Double Fillet Lap Joint. A double fillet lap joint can withstand greater loads than the single fillet and is one of the more widely used joints in welding. If the double fillet weld is properly made, its strength is comparable to that of the base metal.

Corner Joints

A *corner joint* is a joint formed when two workpieces are positioned at an approximate right angle in the shape of an L. Corner joints are used in many applications to join sheet and plate metal sections exposed to general service loads. Common corner joints are flush, half-open, and full-open. See Figure 3-10.

A lap joint is usually welded on both sides of the joint.

Corner Joints
Figure 3-10

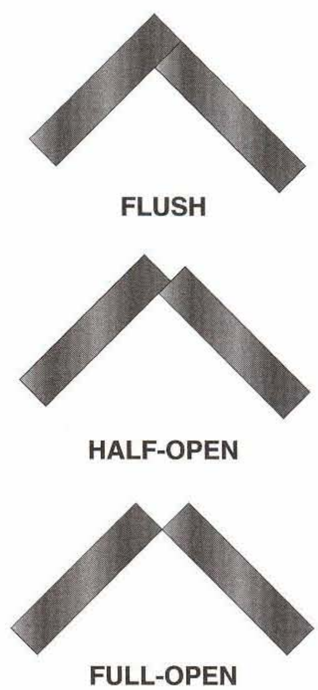


Figure 3-10. *Corner joints are generally used only where severe loads are not encountered.*

Flush Corner Joints. A flush corner joint is designed primarily for welding sheet metal 12 gauge and lighter. It is restricted to light materials because deep penetration is sometimes difficult to achieve, and the joint is able to support only moderate loads.

Half-Open Corner Joints. A half-open corner joint is usually more adaptable for materials heavier than 12 gauge. It is suitable for loads where fatigue or

impact are not too severe and where the welding can only be done from one side. The two edges of the workpieces are shouldered together so there is less tendency to burn through the plates at the corner.

Full-Open Corner Joints. A full-open corner joint permits welding on both sides so it produces a strong joint capable of carrying heavy loads. All metal thicknesses can be welded with full-open corner joints. A full-open corner joint provides good stress distribution.

ESAB Welding and Cutting Products

The weld type used must be designed for the particular joint to be welded and the load requirements of the weld.

Edge Joints

An *edge joint* is a weld joint formed when the edges of two or more parallel or nearly parallel members are joined. The edge joint is suitable for plates ¼″ thick or less and can sustain only light loads. Edge joints can be combined with butt joints or corner joints and the edges can be squared or beveled. See Figure 3-11. An edge joint is commonly used to join support structures and short lengths of structural steel. A *flanged joint* is a joint in which one of the joint members has a flanged edge at the weld joint.

Edge Joints
Figure 3-11

Figure 3-11. *Edge joints are commonly used for light load applications. Many combinations of joint edges are possible since edge joints can be square or beveled.*

WELD TYPES

A *weld type* is the cross-sectional shape of the weld after filler metal is added to the joint. The weld type differs from the weld joint in that the weld type indicates the way in which filler metal is added while the weld joint is the configuration of the joint members. The weld type used is determined by the weld joint design and depends on the load requirements of the weld. To maximize weld strength and economy, the following basic rules are observed:

- Minimize edge preparation. Minimizing edge preparation reduces cutting and machining costs.
- Provide weld access. Allow for access to the weld by welding machinery. The welding equipment available for the job must be considered.
- Minimize filler metal. Minimizing filler metal reduces costs.

- Reduce excess heat. Reducing the amount of excess heat applied to the weld area during welding minimizes metallurgical changes of the base metal and filler metal.
- Minimize the number of welds. Minimizing the number of welds reduces the filler metal required. Additionally, distortion of joint members from heat application is reduced.
- Size the weld for the thinnest joint member. The size of the weld should not exceed the strength of the thinnest joint member.

Joint design selection uses root openings and groove openings that require the least amount of weld metal yet still provide accessibility to the joint. Joint design selection is also influenced by the type of metal to be welded, the location of the joint in the weldment, and the required performance of the weld. Weld joints and types are selected for specific applications.

Weld types include fillet weld, groove weld, plug or slot weld, surfacing weld, stud weld, spot and seam weld, projection weld, and back weld. See Figure 3-12.

Fillet Welds

A *fillet weld* is a weld of approximately triangular cross section that joins two surfaces at approximately right angles. Fillet welds may be used for lap, T, or corner joints. Fillet welds are the most commonly used weld type and are preferred over groove welds because they are easier to prepare and are less expensive to complete. Fillet welds may be made from one side (single fillet weld) or both sides (double fillet weld). Fillet weld size is specified by the lengths of the legs of the largest right triangle that may be inscribed within the fillet weld cross section.

Fillet welds are commonly used when load stresses are low and the required effective throat is less than 5⁄8″. The strength of the fillet weld is based on the effective throat of the weld. If the load requires an effective throat of 5⁄8″ or larger, a groove weld should be used, possibly in combination with a fillet weld to provide the required size.

Groove Welds

A *groove weld* is a weld made in the groove between the two workpieces to be joined. A groove weld may be square groove, single-groove, or double-groove. A square groove weld is economical, but its use is limited by the thickness of the joint and the service load. A groove weld is adaptable for a variety of joints, most commonly the butt joint. The groove weld should use the smallest root opening and groove angle possible for the job to provide a sound weld using the least amount of filler metal.

With a suitable opening and backing strip, square groove weld joints up to 1⁄4″ thick can be made by SMAW. Square groove weld joints up to 3⁄8″ thick can be made with GMAW, FCAW, and SAW. The root of a square groove weld should not be under tension when the weld is bent under load.

Single-groove and double-groove welds are normally used for thick joints. A *single-groove weld* is a groove weld that is made from one side only. Single-groove welds include single-square-groove, single-bevel-groove, single-V-groove, single-J-groove, single-U-groove, single-flare-bevel-groove, and single-flare-V-groove. A *double-groove weld* is a groove weld that is made from both sides. Double-groove welds include double-square-groove, double-bevel-groove, double-V-groove, double-J-groove with backing, double-U-groove, double-flare-bevel-groove, and double-flare-V-groove. The edge of each workpiece must be prepared to provide accessibility for welding and to ensure the desired soundness and strength. The selection of a single-groove weld over a double-groove weld is principally dictated by cost.

Groove welds are very adaptable for a variety of joints, but their use is limited by the thickness of the material.

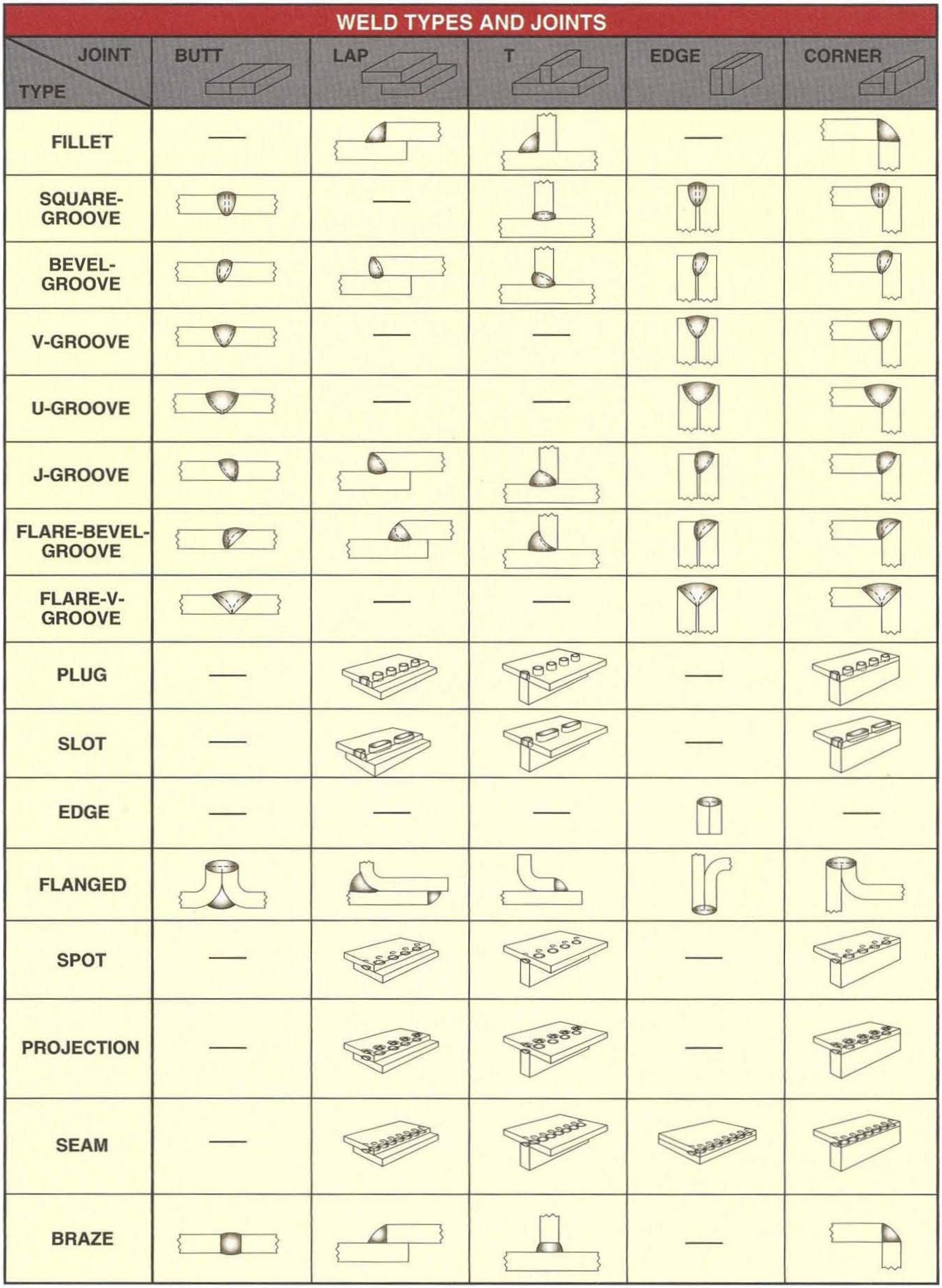


Figure 3-12. *The basic weld joints are used with applicable weld types to meet load requirements.*

Plug or Slot Welds

Plug welds and slot welds may be used to join two overlapping pieces of metal by welding through circular holes or slots. A *plug weld* is a weld made in a circular hole in one workpiece, fusing that workpiece to another workpiece. A hole is cut in one workpiece, which is then positioned over the second workpiece. The weld is made through the hole. A *slot weld* is a weld made in an elongated hole in one workpiece of a joint, fusing that workpiece to another workpiece. The circular hole or slot may be open at one end. Welding is done by completely filling the circular hole or slot to join the two workpieces. Plug welds and slot welds are often used instead of rivets.

Plug and slot welds should not be confused with fillet welds because the base of the circular hole or slot is completely filled. A fillet weld only deposits its filler metal in a triangular shape on the perimeter of the circular hole or slot. Plug welds were originally used during design transitions from riveted to welded structures and are most commonly used for joining sheet to a substrate to provide protection such as corrosion resistance.

Surfacing Welds

A *surfacing weld* is a weld applied to a surface, as opposed to a joint, to obtain desired properties or dimensions. Surfacing welds are commonly used to strengthen selected surfaces of a single component, such as an extruder. A surfacing weld applied to increase wear resistance is known as hardfacing or fusion hardfacing. Surfacing welds do not require preparing an actual weld joint.

A surfacing weld is different from thermal spraying. *Thermal spraying (THSP)* is a group of processes in which finely divided metallic or nonmetallic materials are deposited in a molten or semi-molten condition to form a coating. The surfacing material may be in the form of a powder, rod, cord, or wire. THSP is also called arc spray, flame spray, and plasma spray. Thermal spray hardfacing (non-fusion hardfacing) is the application of a thin layer of materials to the surface in such a way that local melting does not occur.

Stud Welds

A *stud weld* is a weld produced by joining a metal stud or similar part to a workpiece. During the welding process, part of the stud is melted, providing weld reinforcement at the base of the stud. Welding may be done with heat and pressure.

Spot and Seam Welds

A spot weld and seam weld are, respectively, circular cross-sectional or continuous welds made between overlapping members in which coalescence may start and continue on the faying surfaces, or may proceed from the outer surface of one member to the faying surface. A *faying surface* is the mating surface of a member that is in contact with or in close proximity to another member to which it is to be joined.

A *spot weld* is a weld made between overlapping workpieces in which coalescence forms a series of circular cross sections. A *seam weld* is a continuous weld between overlapping workpieces in which coalescence produces a continuous seam or series of overlapping spot welds.

Projection Welds

A *projection weld* is a resistance weld produced by the heat obtained from the resistance to the flow of welding current. The resulting welds are localized at predetermined points by projections, embossments, or intersections. Spot and projection welds are specified in pounds per weld. Seam welds are

A plug weld or slot weld is used to join overlapping pieces of metal through circular holes or slots made in one member.

specified in pounds per inch of joint strength. A weld strength greater than the strength of the minimum nugget size should be specified in the design. A *nugget* is the weld metal that joins the workpieces in spot, seam, or projection welds.

Back Welds

A *back weld* is a weld made in the weld root opposite the face of the weld. A back weld is deposited after welding on the face side of the workpiece is completed. Back welds are usually made to improve the quality of the first pass of weld metal (root pass). This is achieved by gouging or grinding out imperfections in the root pass, followed by depositing the back weld.

WELD DESIGNS

Weld joint designs are governed by AWS codes and other appropriate codes. For example, in building construction, AWS codes govern structural and welding materials, weld details, processes and techniques, weld quality, and inspection. The design of the structural elements is governed by American Institute of Steel Construction (AISC) specifications. The weld joint design selected must factor in wind forces, loads, seismic conditions, and other conditions that can cause fatigue. Additional codes such as the Uniform Building Code and other appropriate state and local codes may also apply.

AWS codes are to be used as a guide to design consistent, quality weld joints.

The designer or engineer is responsible for determining the proper weld design to use; however, a welder should be aware of joint design requirements in order to produce a weld that better meets the established specifications for the job.

Weld Joint Selection

Welded joints provide strength and efficiency and can be made more quickly than other joining methods. Welded joints have replaced many parts and structures that previously used fasteners or the casting process. Most welded joints are subjected to loads that require strength and rigidity to prevent failure. Loads in a structure are transferred from member to member through the welds. Welded joints subjected to minimum loads are considered to be "no-load" welds. For example, access covers and panels and safety guards require "no-load" welds.

AWS Welding Positions. Weld joint selection is also affected by the welding position. The four basic welding positions are flat, horizontal, vertical, and overhead. See Figure 3-13. Flat position is the most widely used welding position because welding can be done quickly and easily, and flat position welding allows for the greatest control of the welding process.

In the horizontal, vertical, and overhead positions, gravity reduces penetration and filler metal control, which can cause weld defects resulting in weak welds. Horizontal welding is difficult because the molten pool has a tendency to sag. Vertical welding is done in a vertical line from the bottom to the top or from the top to bottom of the workpieces. On thin material, a downhill welding technique is usually more applicable. Overhead welding is difficult because the molten metal sags. A uniform bead with the proper penetration must be secured.

Small parts are commonly welded in flat position for efficiency. However, some large parts that cannot be positioned for flat-position welding can be controlled using jigs, tack welds, spacers, or consumable inserts.

A *tack weld* is a weld used to hold workpieces in proper alignment until the final welds are made. Subsequent welding on the weld joint melts through the tack welds. Spacers provide a gap between the joint members to be tack welded.

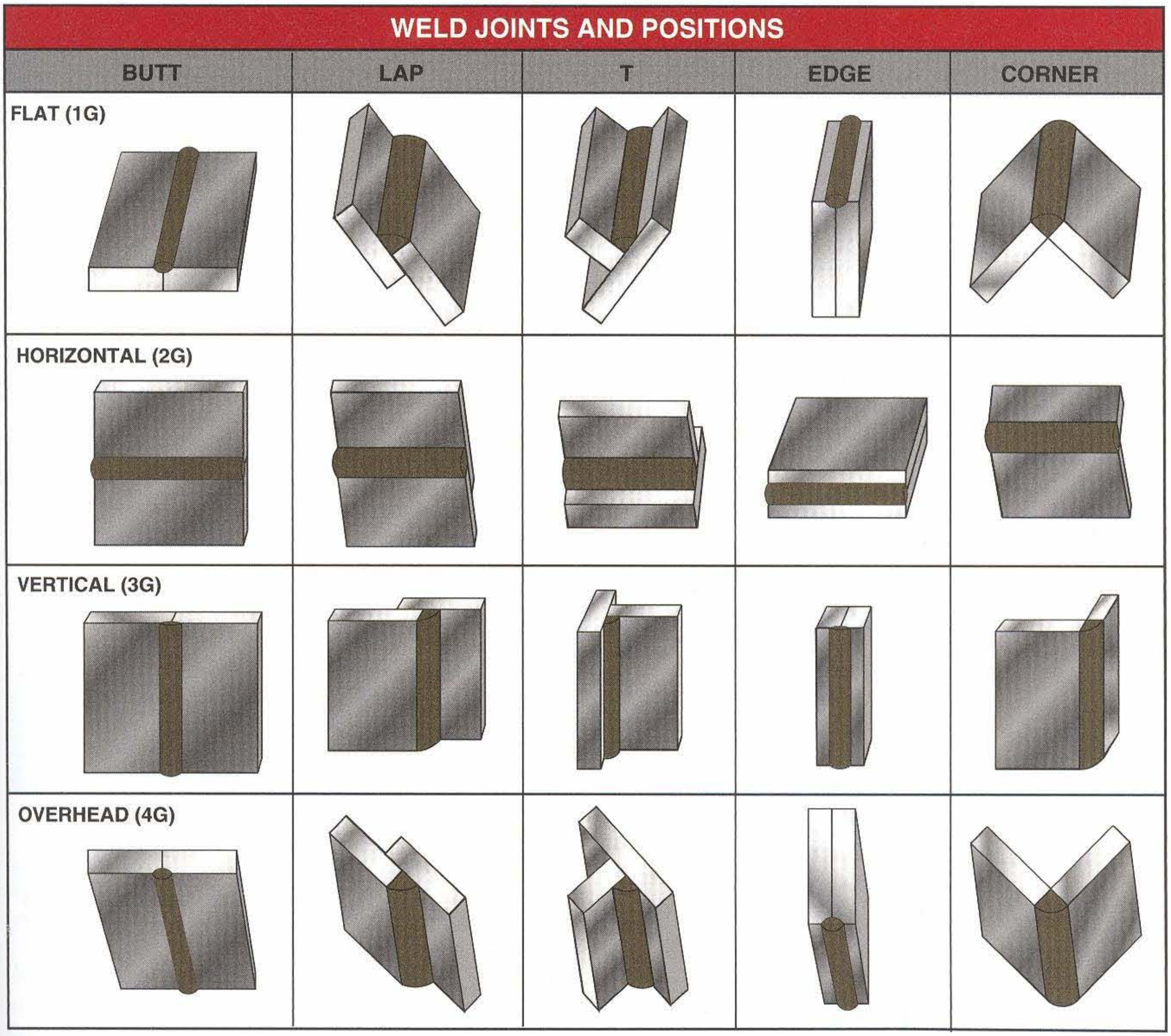


Figure 3-13. *The four common welding positions are flat, horizontal, vertical, and overhead.*

After tack welding, the spacers are removed before continuing the welding process. Consumable inserts are melted during the welding process and become part of the filler metal added to the weld joint.

Joint Preparation. A quality weld is dependent on proper joint preparation. Edges are commonly cut, sawed, or machined to provide good fit-up of parts. Edge preparation for groove welds must also be considered. Fit-up must be consistent through and along the entire joint. The following general requirements provide for proper joint preparation:

- Sheet metal and most fillet and lap joints should be clamped tight for the entire length of the workpiece to be welded. Gaps or bevels must be accurately controlled over the entire joint. Any variation in a given joint forces the welder to adjust the welding speed to avoid melt-through (burn-through) and to use different electrode manipulations to fill the fit-up variation.
- Correct groove angle is required for good bead shape and penetration. See Figure 3-14.

Joint preparation guidelines must be followed closely to provide good fit-up during welding.

Groove Angle
Figure 3-14

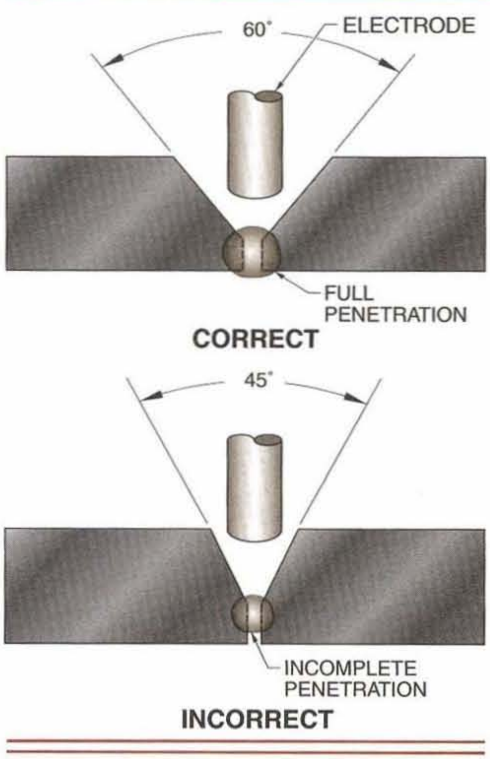


Figure 3-14. *A correct groove angle is essential for a good weld as it allows the weld metal to fully penetrate the root opening.*

An insufficient bevel prevents the electrode from penetrating into the joint. Deep, narrow beads may lack penetration, and they have a tendency to crack. A wide bevel groove is typically used in pipe welding to ensure complete penetration. See Figure 3-15.

Pipe Welding Angle
Figure 3-15

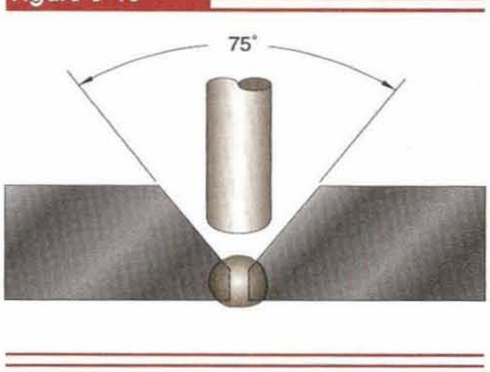


Figure 3-15. *A pipe weld requires a wide 75° groove angle.*

- Proper groove angle of 60° to 75° should be maintained. A sufficient bevel is necessary for a quality bead; however, any excess bevel creates additional work for the welder and wastes filler metal. Filler metal is expensive, and any variation from the recommended groove angle size contributes to excess cost, in both material and time, in making a weld. See Figure 3-16.

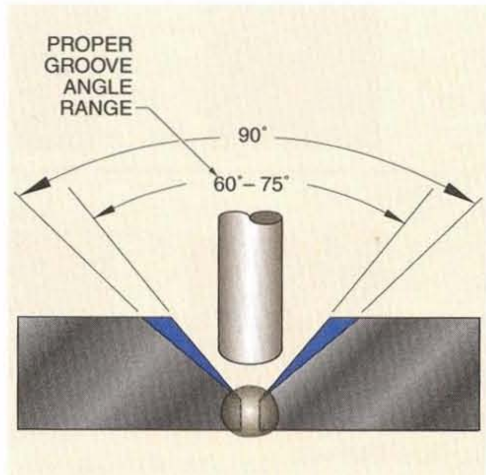


Figure 3-16. *An overly large groove angle wastes filler metal and time, resulting in greater welding costs.*

- Sufficient gap is needed for full penetration. Without adequate penetration, a welded joint cannot withstand the loads imposed on it. Although proper penetration depends to some extent on electrode manipulation, it is essential that the welder provide a correct root opening to achieve full penetration. See Figure 3-17.
- Either a ⅛″ root face or a backing strip is required for fast welding and a good quality weld. Feather-edge preparations require a slow, costly root bead. However, double-V butt joints without a root face are practical when the root bead is offset by easier edge preparations and when the gap can be limited to about ³⁄₃₂″. See Figure 3-18.

Root Opening
Figure 3-17

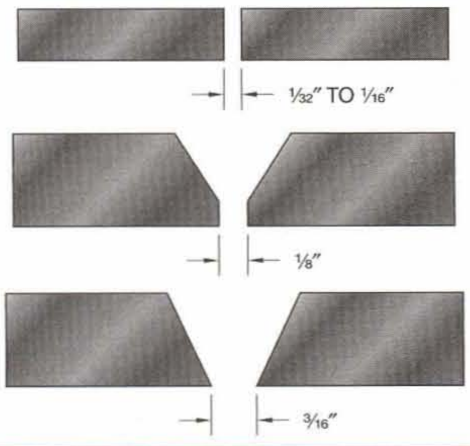


Figure 3-17. *Proper root opening size is required in order to make a sound weld. The root opening size is determined by the wall thickness of the metal.*

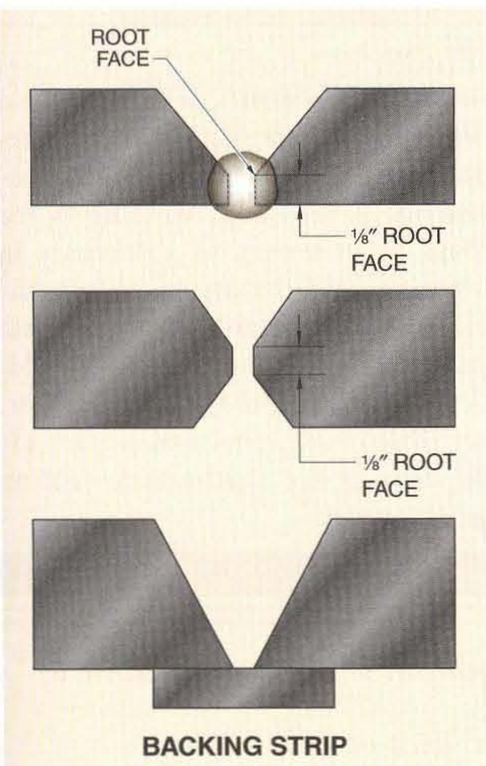


Figure 3-18. *The proper root face must be provided for a quality weld.*

Joint Access. Sufficient access is required for the welding equipment and the deposition of filler metal. For example, the large welding gun required for flux cored arc welding limits the access to welds in tight areas. Proper fit-up also ensures that the workpieces are in correct alignment, have the correct edge preparation, and have the required root opening for proper penetration and sufficient weld reinforcement. See Figure 3-19. Workpieces should be aligned edge-to-edge and end-to-end, and also should lie in the same plane. Subassemblies can eliminate some access problems.

Each weld joint type has certain advantages and limitations. Welders must be especially aware of the limitations, as the effectiveness of the weld is often contingent on the type of joint that is used as well as the skill of the welder. Load requirements dictate the strength of the required welds. Weld types are used with the applicable weld joint, and include fillet, groove, plug or slot, and surfacing welds.

Welding Location. Welding is performed in the shop or in the field, depending upon the size and fabrication requirements of the structure. Small parts, structures, and subassemblies are often welded in the shop. The shop provides a controlled environment in which welding variables can be closely controlled. Additionally, fixtures and positioners can be used to move a part or hold a part in position for improved welding productivity.

The Lincoln Electric Company
Joint design must take into consideration access to the joint by the welder.

Proper Fit-Up
Figure 3-19

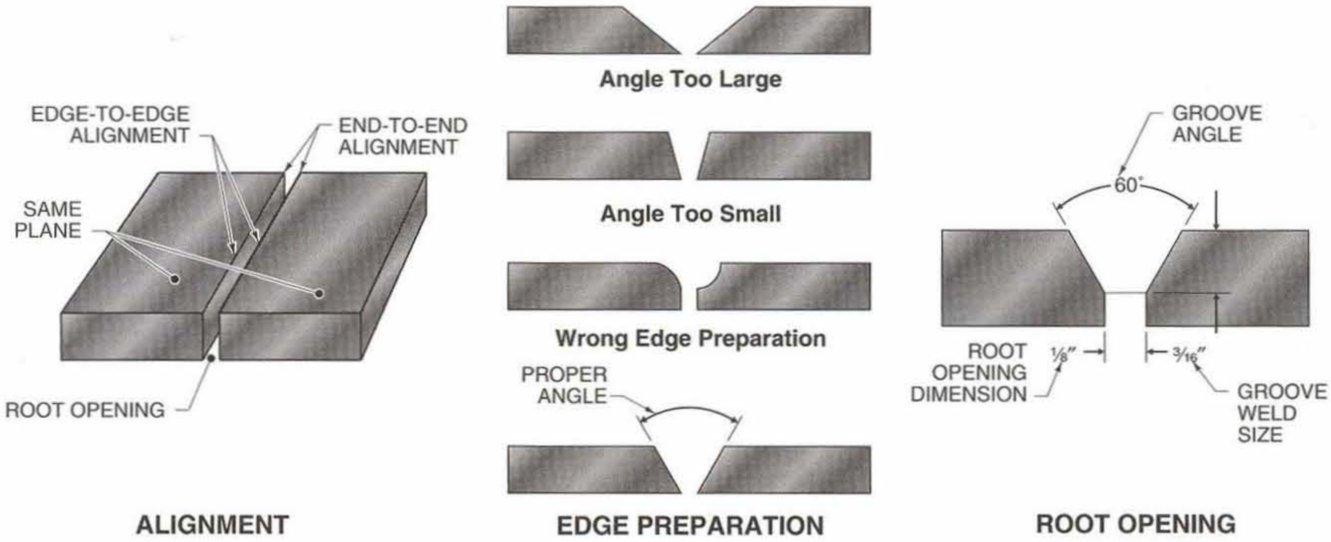


Figure 3-19. *Correct alignment, edge preparation, and root opening are necessary for proper fit-up.*

A *fixture* is a device used to maintain the correct positional relationship between workpieces as required by print specifications. A *positioner* is a mechanical device that supports and moves workpieces for maximum loading, welding, and unloading efficiency.

Positioners can be used with hand- and machine-controlled welding machinery. In production settings, positioners and welding equipment are used together for maximum welding efficiency.

Welding is performed in the field when the size or fabrication requirements of the structure prohibit assembly in the shop. Welding in the field often results in a decrease in welding productivity because additional variables are introduced that can influence the finished weld. Ambient temperature, weather, welding conditions, and welder efficiency in the field affect welding productivity.

POINTS TO REMEMBER

1. The root pass is the initial weld pass that provides complete penetration through the thickness of the joint member.
2. Square butt joints should be used primarily with materials 3/16″ thick or less.
3. A double-V butt joint is suitable for all load conditions.
4. A T-joint is formed when two members are positioned approximately 90° to one another.
5. A lap joint is usually welded on both sides of the joint.
6. Groove welds are very adaptable for a variety of joints, but their use is limited by the thickness of the material.
7. A plug weld or a slot weld is used to join overlapping pieces of metal through circular holes or slots made in one member.
8. AWS codes are intended as a standard guide by which to design consistent, quality weld joints.
9. Joint preparation guidelines must be followed closely to provide good fit-up during welding.

QUESTIONS FOR STUDY AND DISCUSSION

1. What factors must be considered when determining the type of joint to use in welding any structural unit?
2. What is a fillet weld?
3. In what type of joints are groove welds made?
4. What is a plug weld?
5. When is a surfacing weld used?
6. Why are grooved butt joints better for welding thick plates than square butt joints?
7. What are the basic types of T-joints?
8. Describe a double fillet lap joint.
9. Which type of corner joint is the strongest?
10. What is the toe of a weld?
11. What is the root of a weld?
12. What are some of the basic principles that contribute to good joint-geometry?
13. When are double bevel T-joints normally used?
14. Which butt joint requires the least amount of preparation before welding?
15. What is reinforcement of the weld?
16. How is the root opening size determined?
17. Why is a proper groove angle required?
18. How is the size of a weld leg determined?

OAW–Equipment 4

Oxyacetylene welding does not require electricity and is typically used for maintenance, in body shops, and in the repair of small parts where other welding processes are too expensive.

Oxyacetylene welding can be used to join iron, steel, cast iron, copper, brass, aluminum, bronze, and other metals. Often, dissimilar metals such as steel and cast iron, brass and steel, copper and iron, and brass and cast iron can be joined with oxyacetylene welding. Oxyacetylene welding equipment can also be used for preheating, cutting metal, case hardening, and annealing.

OXYGEN FOR WELDING

The atmosphere (air) is comprised of approximately 20% oxygen. The majority of the atmosphere is made up of nitrogen with a percentage of rare gases such as helium, neon, and argon. For oxygen to be usable for welding, it must be separated from the other gases. The two methods that can be used to isolate oxygen are the liquid-air and the electrolytic methods.

The liquid-air method of producing oxygen draws air from the atmosphere into huge containers called washing towers. In the washing towers, the air is washed and purified of carbon dioxide. A solution of caustic soda is circulated through the towers by means of centrifugal pumps to wash the air.

As the air moves out of the washing towers, it is compressed and passed through oil-purging cylinders. In the oil-purging cylinders, oil particles and water vapor are removed. From the oil-purging cylinders, the air moves into drying cylinders. The drying cylinders contain dry, caustic potash that dries the air and removes any remaining carbon dioxide and water vapor. At the top of each drying cylinder are special cotton filters to prevent particles of foreign matter from being carried into the high-pressure lines.

The dry, clean, compressed air then goes into rectifying or liquefaction columns where the air is cooled and expanded to approximately atmospheric pressure. As the pressure is lowered, the extremely high-pressure, cold air cools and liquefies.

Thermadyne Industries, Inc.

A mixture of oxygen and acetylene is used for most welding and cutting operations.

The separation of the nitrogen from the oxygen is possible once the air has liquefied because nitrogen and oxygen have different boiling points. Nitrogen boils at –320°F (–195.5°C) and oxygen at –296°F (–182°C). The nitrogen, having a lower boiling point, evaporates first, leaving the liquid oxygen at the bottom of the condenser. The isolated liquid oxygen passes through a heated coil, which changes the liquid oxygen into a gaseous form. After the gas moves through the heated coil, it is stored in a storage tank. A gas meter mounted between the heating coil and the storage tank registers the amount of gas entering the storage tank. The stored oxygen gas can then be drawn from the storage tank and compressed into receiving cylinders.

The electrolytic method is a process that uses water and electricity to isolate oxygen. Water is a chemical compound consisting of oxygen and hydrogen. By sending an electrical current through a solution of water containing caustic soda, oxygen is given off at one terminal plate, and hydrogen at the other. The oxygen, having been separated from the hydrogen, is suitable for welding. The electrolytic method is a very expensive method of producing oxygen; for this reason the liquid-air method is more commonly used to produce commercial oxygen.

Handle oxygen and acetylene cylinders with care. Never expose them to excessive heat and prevent contact with oil and grease.

Oxygen Cylinders

Oxygen cylinders are made from seamless drawn steel and tested with a water (hydrostatic) pressure of 3360 psi. The cylinders are equipped with a high-pressure valve that can be opened by turning the handwheel on top of the cylinder. The valve handwheel should always be opened by hand and not with a wrench. The handwheel must be turned slowly to permit a gradual pressure load on the regulator. The valve handwheel is turned to full open position. This provides a seal to reduce leakage from the valve. A protector cap screws onto the neck ring of the cylinder to protect the valve from damage. The protector cap must always be in place when the cylinder is not in use. See Figure 4-1.

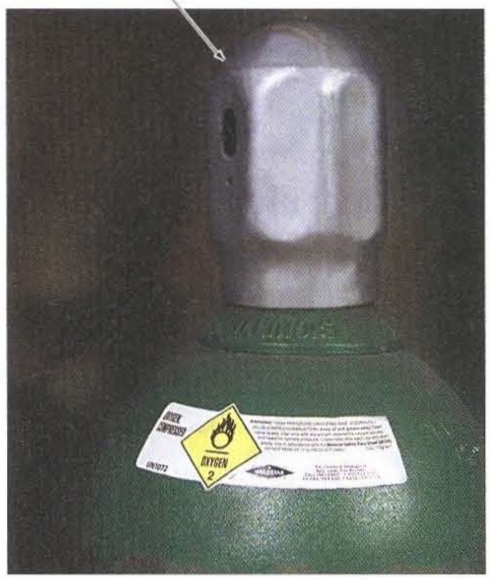


Figure 4-1. *A protector cap screws onto the neck ring of the cylinder to protect the valve from damage when not in use.*

There are three common sizes of oxygen cylinders. The large cylinder holds 244 cubic feet (cu ft) of oxygen. The large size is commonly used in industrial plants and shops that require large quantities of gas. A medium-size cylinder can contain 122 cu ft of oxygen and a small cylinder can hold 80 cu ft.

Cylinders are charged with oxygen at a pressure of 2200 psi at a temperature of 70°F (21°C). Gases expand when heated and contract when cooled, so the oxygen pressure will increase or decrease as the temperature changes. For example, if a full cylinder of oxygen is allowed to stand outdoors in near-freezing temperatures, the pressure of the oxygen will register less than 2200 psi. However, none of the oxygen has been lost; cooling has only reduced the pressure of the oxygen.

Since the pressure of gas varies with the surrounding temperature, all oxygen cylinders are equipped with a safety nut that permits the oxygen to drain slowly if the temperature increases the cylinder pressure beyond its rated safety load. If a cylinder were exposed to a hot flame, the safety nut would relieve the pressure before the cylinder reached its exploding point.

ACETYLENE FOR WELDING

Acetylene is a colorless gas with a very distinctive, nauseating odor that is highly combustible when mixed with oxygen. Although it is very stable at low pressures, it becomes very unstable if compressed to more than 15 psi.

Acetylene gas is formed by the mixture of calcium carbide and water. The commercial generator in which the gas is produced consists of a huge tank containing water. A specified quantity of carbide is put into a hopper and raised to the top of the generator. The carbide is then allowed to fall into the water. As the carbide meets the water, bubbles of gas are given off. The gas is collected, purified, cooled, and slowly compressed into cylinders.

Acetylene Cylinders

To ensure the safe storage of acetylene, the cylinder is packed with a porous material. This porous material is saturated with acetone, which is a chemical liquid that dissolves or absorbs large quantities of acetylene under pressures greater than 15 psi without changing the nature of the gas. The acetylene cylinder is equipped with a fusible plug that melts, relieving excess pressure, if the cylinder is subjected to any mechanical pressure or undue heat, such as from a fire. See Figure 4-2. Acetylene cylinders should never be laid down as the corrosive nature of the acetone can erode the seals in the tanks.

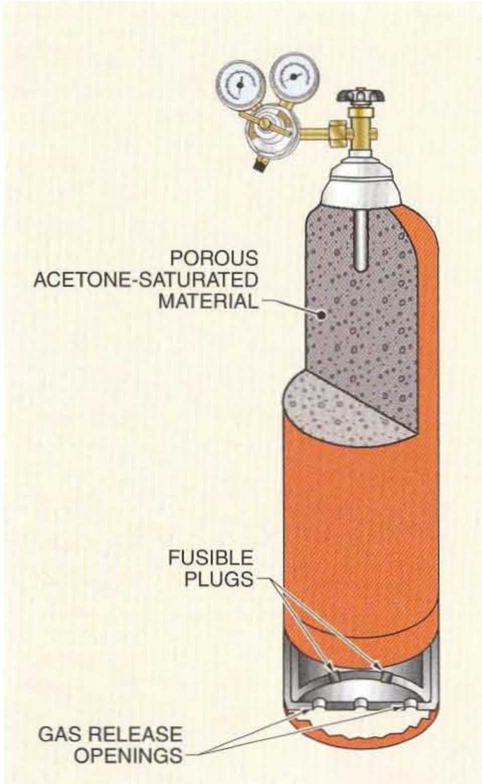


Figure 4-2. *An acetylene cylinder is packed with a porous material that is saturated with acetone to allow the safe storage of acetylene.*

⚠ WARNING

Acetylene becomes dangerous and unstable if compressed to more than 15 psi of pressure.

The cylinder valve is opened with an installed valve handle. See Figure 4-3. The cylinder valve should never be opened more than one complete turn. It is advisable to open the cylinder only slightly so the valve can be closed quickly in case of an emergency.

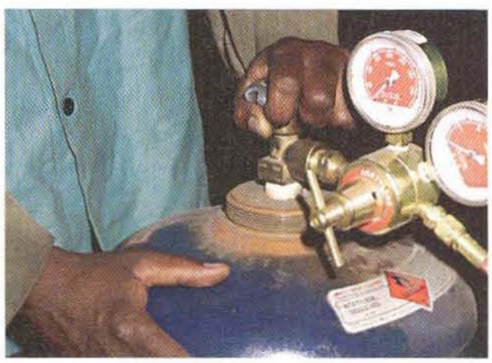


Figure 4-3. *The acetylene cylinder valve should be opened with the installed valve handle.*

When a considerable amount of welding is to be performed in an area, as in industry or in a school welding shop, acetylene cylinders are frequently connected to a manifold system with pipelines carrying the gas to the welding stations. See Figure 4-4. The demand for acetylene is usually higher than can be supplied by a

single cylinder, so a manifold system is commonly needed. A multiple cylinder manifold system allows the necessary volume of acetylene to be supplied to the work area. Acetylene can be drawn off no faster than one-seventh the total volume of the cylinder per hour, which is the quickest the acetylene can be released from the acetone lining in the cylinder. A flash arrestor is also used in the manifold system to prevent a flashback from reaching the stored cylinders.

ESAB Welding and Cutting Products

Figure 4-4. *Acetylene cylinders are connected to a manifold system in areas where a high volume of welding is to be performed.*

Flash Arrestors. A *flash arrestor* is a safety device that prevents an explosion or a backfire in the torch or torch head from reaching the regulator and the acetylene cylinder. Two types of flash arrestors are the torch-mounted and the regulator-mounted.

The torch-mounted flash arrestor is a check valve that prevents a reverse gas flow from reaching the cylinder. The regulator-mounted flash arrestor is a combination check valve and flame barrier. The barrier metal is a porous flame-retardant material that allows gas to flow through, but blocks out a flame. Torch-mounted and regulator-mounted flash arrestors should always be used on fuel hoses and oxygen hoses. Regulator-mounted flash arrestors prevent backfires and flashbacks from entering the hoses, and possibly the cylinders.

⚠ WARNING

Never move cylinders with regulators attached. Always remove the regulators and install the protective cap prior to moving.

A backfire is caused by the flame going out suddenly on the torch. A backfire may occur when the tip is touched against the workpiece; if the flame settings are too low; if the tip is dirty, damaged, or loose; or if the tip is overheated.

When a torch backfires, it could cause a flashback. A flashback is a condition in which the flame burns inside the tip, the torch, or the hose. In case of a flashback, the oxygen and fuel valves must be immediately closed to prevent possible explosion of the cylinders. Flashbacks are typically caused by malfunctioning equipment. If a flashback occurs, the equipment should be removed from service and a service technician called to correct the problem or replace the equipment. Hoses should be discarded after a flashback. The torch tip is reusable, but it should be removed from the torch and thoroughly blown out with air to remove any soot or residue.

SAFE HANDLING OF CYLINDERS

To move a cylinder, rotate it on its bottom edge. Place the palm of one hand over the protector cap and tilt the cylinder backward onto the edge. Start the cylinder rolling by pushing it with the other hand. See Figure 4-5. Follow these safety precautions when handling oxygen and acetylene cylinders:

- Never lift a cylinder by the protector cap.
- Always keep cylinders in a vertical position.
- Do not allow grease or oil to come in contact with cylinder valves. Although oxygen is in itself nonflammable, it quickly aids combustion if exposed to flammable materials.
- Avoid exposing cylinders to furnace heat, radiators, open fire, or sparks from a torch.

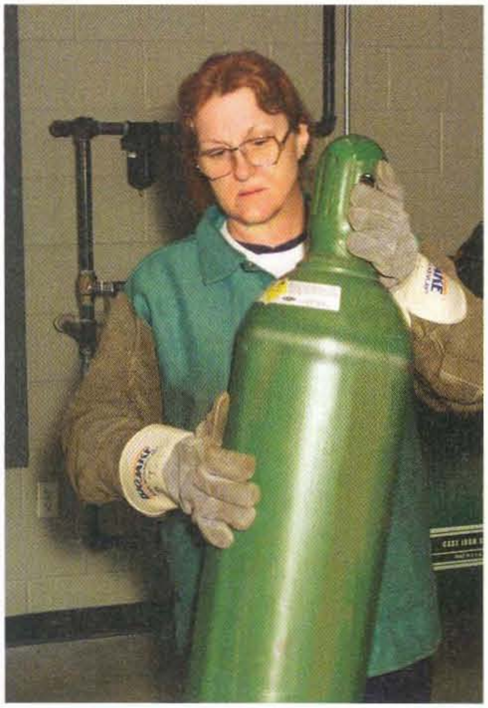


Figure 4-5. *To safely move a cylinder, tilt the cylinder backward with one hand and roll the cylinder, guiding the cylinder with the other hand.*

Figure 4-6. *Cylinders should be chained at all times during use and when stored.*

- Never transport a cylinder by dragging, sliding, or rolling it on its side. Avoid striking it against any object that might create a spark, as there may be just enough gas escaping from the cylinder to cause an explosion.
- Shut OFF cylinder valves completely before moving cylinders.
- Do not tamper with or attempt to repair cylinder valves. If valves leak or do not function properly, notify the supplier immediately.
- Keep valves closed on empty cylinders.
- Do not use a hammer or wrench to open cylinder valves. If they cannot be opened by hand or with a T-wrench, notify the supplier.
- Keep cylinders covered with valve protector caps when not in use.
- Cylinders should be chained in position at all times during use and when stored. Cylinders in use should be securely attached to a hand cart, or chained near the work station. See Figure 4-6.

WELDING APPARATUS

The welding apparatus consists of a torch with an assortment of different-sized tips; two lengths of hose, one red for acetylene and the other green for oxygen; two pressure regulators; two cylinders, one containing acetylene and the other oxygen; a welding sparklighter; and a pair of goggles. See Figure 4-7.

Cylinders are typically chained to a two-wheel hand truck to permit moving the equipment to a desired location. If the cylinders are positioned near the workbench, they should be chained to a fixed object.

Welding Torches

The welding torch, or blowpipe, is a tool that mixes acetylene and oxygen in the correct proportions and permits the mixture to flow to a tip, where it is burned. Although torches vary to some extent in design, they are made to provide complete control of the flame during the welding operation. See Figure 4-8.

Figure 4-7. *Cylinders can be chained to a two-wheel hand truck for easy transportation.*

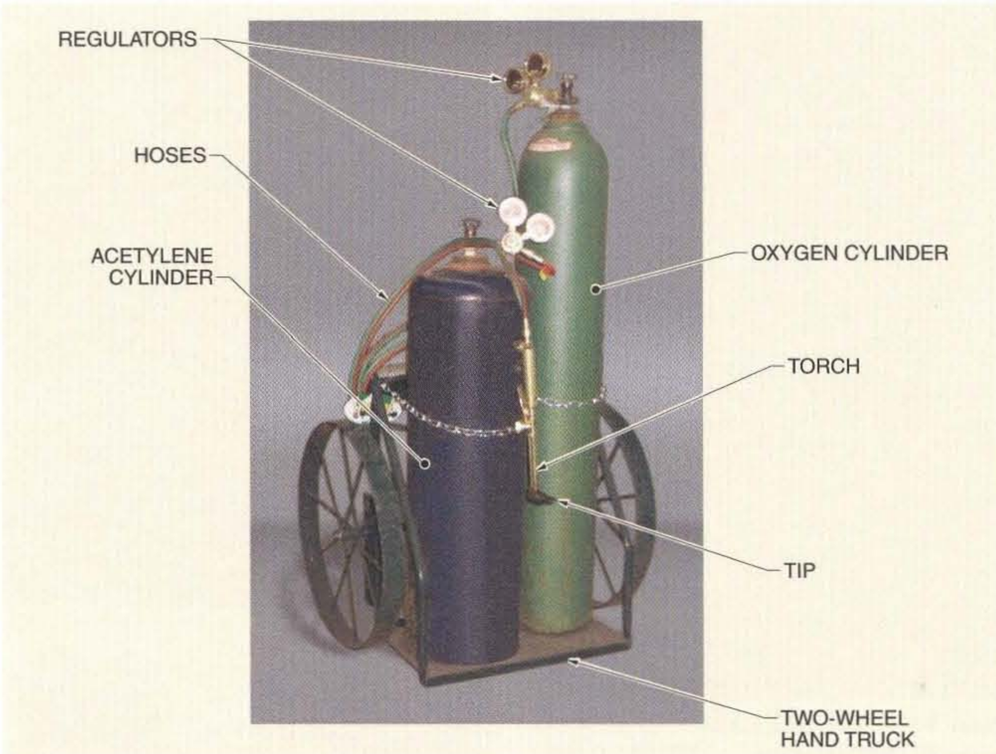
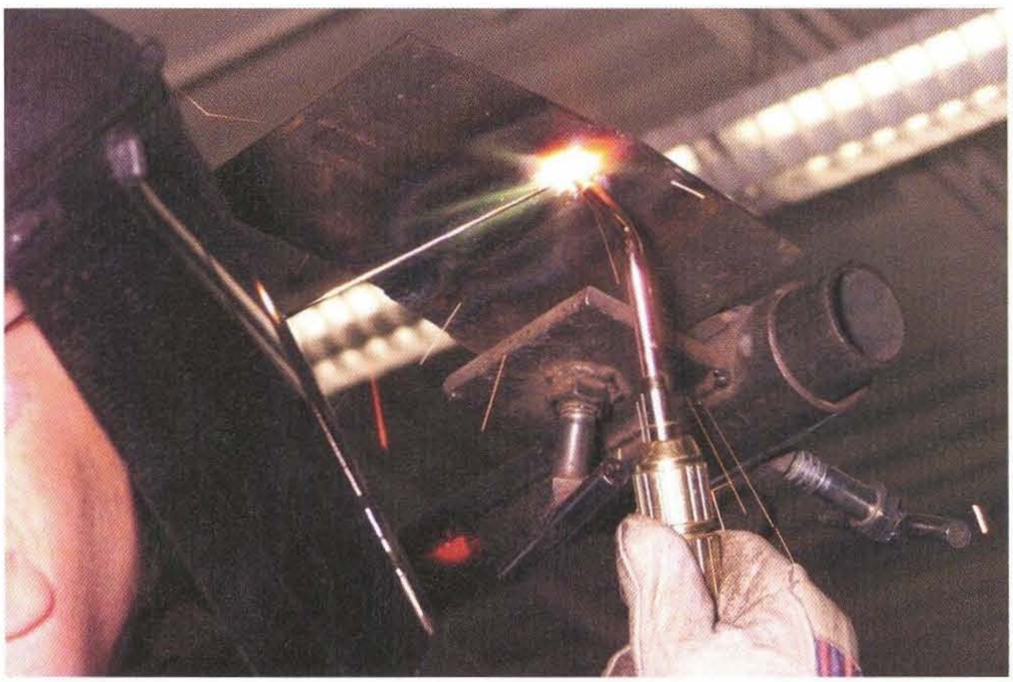


Figure 4-8. *An oxyacetylene welding torch provides complete control of the flame during welding.*



The two primary types of torches are the medium-pressure and the injector. The medium-pressure torch requires acetylene pressures of 1 psi to 10 psi. The injector torch is designed to use acetylene at very low pressures (0 up to 1 psi). Both types of torches operate when acetylene is supplied from cylinders or medium-pressure generators.

⚠ CAUTION

Cylinders must be properly secured; otherwise, they may tip over and ruin the regulators or cause an explosion.

In a medium-pressure torch, the oxygen and acetylene are fed independently to a mixing chamber, after which they flow out through the tip. In an injector torch, the oxygen, as it passes through a small opening in the injector nozzle, draws acetylene into the oxygen stream. When small fluctuations in the oxygen supply occur, a corresponding change

occurs in the amount of acetylene drawn, maintaining consistent proportions of the two gases while the torch is in operation. The medium-pressure torch is the most commonly used torch.

Both types of torches are equipped with two needle valves; one regulates the flow of oxygen at the torch and the other regulates the flow of acetylene at the torch. At the base of the torch are two fittings for connecting each hose. To eliminate any chance of interchanging the hoses, the oxygen fitting is made with a right- hand thread and the acetylene fitting is made with a left-hand thread.

Care of Torches. When welding is completed, the torch should be properly secured to prevent it from falling and becoming damaged. Needle valves are especially delicate, and if the torch drops and strikes a hard object, the needle valves can break easily. Needle valves may loosen and turn too freely, making it difficult to keep the proper adjustment for the required mixture. When the needle valves loosen, the packing nuts on the stem of the needle valves should be tightened with a slight turn of a wrench. See Figure 4-9.

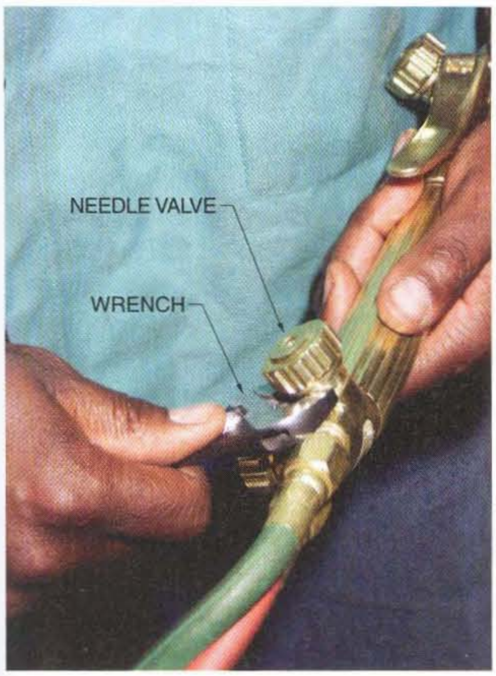


Figure 4-9. *The packing nuts on the stem of the needle valves are tightened with a correctly fitting wrench.*

Welding Tips

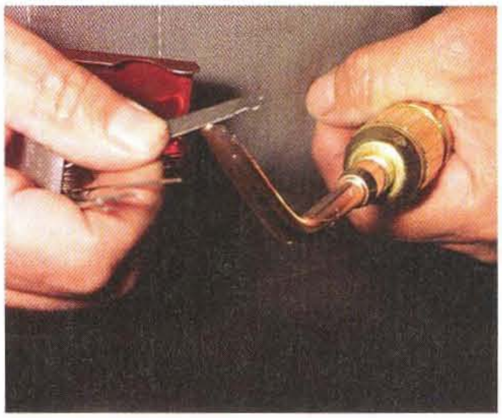
Welding on different thicknesses of metal is possible because torches are equipped with an assortment of different size heads, or tips. The size of the tip is governed by the diameter of its opening, which is marked on the tip.

Care of Welding Tips. A welding tip is designed to be installed and removed by hand. Frequent torch use causes carbon to form in the passage of the tip. Carbon must be removed from the tip regularly to ensure the free flow of gas. See Figure 4-10. To clean a torch tip, follow the procedure:

1. File the end of the tip flat with a metal file.
2. Insert a properly-sized tip cleaner into the tip and pull it straight out. Repeat until the tip is clean.

Always hang up a torch when not in use to prevent it from dropping to the floor and being bent or damaged.

Cleaning a Torch Tip
Figure 4-10



(1) FILE TIP FLAT

(2) INSERT TIP CLEANER

Figure 4-10. *A tip cleaner is used to clean a torch tip.*

⚠ CAUTION

Never remove welding tips with pliers. If a tip has to be cleaned, use a tip cleaner.

Regulators

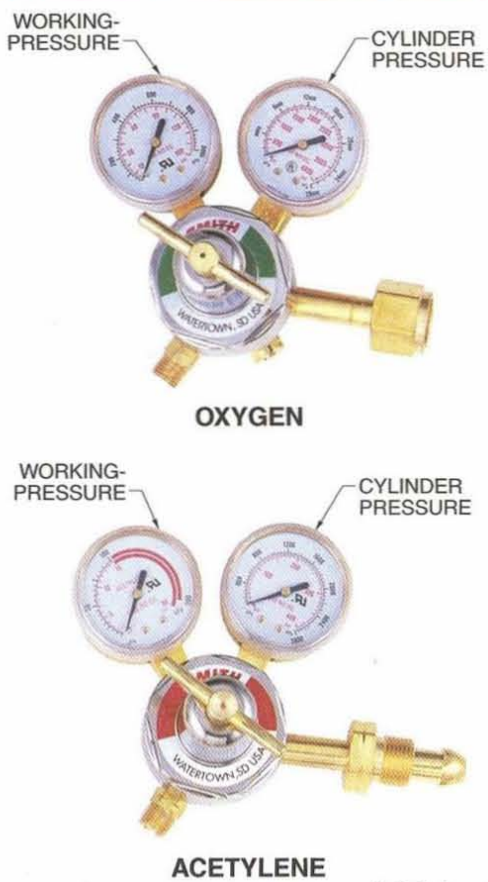
Oxygen and acetylene pressure regulators perform two functions. They control the flow of gas from the cylinder to maintain the required working pressure, and they produce a steady flow of gas under varying cylinder pressures. Regulators are equipped with two gauges—a cylinder pressure gauge, which indicates the actual pressure in the cylinder, and a working-pressure gauge, which shows the working, or line, pressure used at the torch. The oxygen cylinder pressure can be as high as 2200 psi. The required working pressure for oxygen is from 1 psi to 25 psi. The acetylene cylinder pressure can be as high as 250 psi. The working pressure for acetylene must be between 1 psi and 12 psi. The regulator must maintain the proper working pressure, even as the cylinder pressure changes. If the oxygen in the cylinder is under a pressure of 1800 psi and a pressure of 6 psi is needed at the torch, the regulator must maintain a constant pressure of 6 psi even if the cylinder pressure drops to 500 psi.

The oxygen cylinder pressure gauge is a graduated scale up to 4000 psi. A second scale on the gauge is calibrated to register the contents of the cylinder in cubic feet. The oxygen working-pressure gauge is graduated in divisions from 0 psi to 60 psi and the acetylene working-pressure gauge is graduated in divisions from 0 psi to 30 psi. The acetylene working-pressure gauge is usually marked with a warning color above 15 psi. The acetylene cylinder pressure gauge is graduated up to 350 psi or 400 psi. See Figure 4-11.

Be sure the adjusting screw on a regulator is fully released before opening a cylinder valve.

The two types of regulators are the single-stage and the two-stage. The single-stage regulator is typically less expensive than the two-stage type. With the single-stage regulator, there is no intermediate chamber through which gas passes before it enters the low-pressure chamber. The gas from the cylinder flows into the regulator and is controlled entirely by the adjusting screw.

Regulators
Figure 4-11



Smith Equipment

Figure 4-11. *Oxygen and acetylene regulators control the flow of gas to be used for welding.*

A single-stage regulator must be continually adjusted to maintain correct working pressure. The adjusting screw on a regulator must be released (turned out) before the cylinder valve is opened. If the adjusting screw is not released and the cylinder valve is opened, the tremendous pressure of the gas in the cylinder, forced onto the working-pressure gauge, may blow out the screw and damage the regulator.

The adjusting screw is turned to increase or decrease the gas pressure from the torch to the regulator by controlling the force of a spring on the flexible diaphragm. The diaphragm moves a valve, allowing gas to flow into the regulator. As the gas pressure in the regulator increases, it bends the diaphragm back, closing the valve. During welding, the regulator reduces the gas pressure behind

the diaphragm and the spring opens the valve, allowing gas to flow. The change in internal pressure is registered on the working-pressure gauge.

With the two-stage regulator, the reduction of the cylinder pressure to that required at the torch is accomplished in two stages. In the first stage, the gas flows from the cylinder into a high-pressure chamber. A spring and diaphragm keep a predetermined gas pressure in the chamber. For oxygen, the pressure is usually 200 psi, and for acetylene, 50 psi. From the high-pressure chamber, the gas passes into a reducing chamber. Control of the pressure in the reducing chamber is governed by an adjusting screw.

When acetylene and oxygen are mixed correctly and ignited, the flame can reach temperatures of 5700°F (3150°C) to 6300°F (3482°C), which melts commercial metals so completely that they flow together to form a complete bond without the application of any mechanical pressure or hammering. Filler metal is usually added to the molten metal to build up the joint for greater strength. On very thin metals, the edges are generally flanged and melted together. In either case, if the weld is performed correctly, the section where the bond is made is as strong as the base metal.

Care of Regulators. Regulators are sensitive instruments and must be treated as such. A slight jolt can render a regulator useless. Regulators should be handled extremely carefully when being removed from the cylinder. Never leave a regulator on a bench top or floor for any length of time as it could be moved and damaged. General guidelines for the care of regulators include the following:

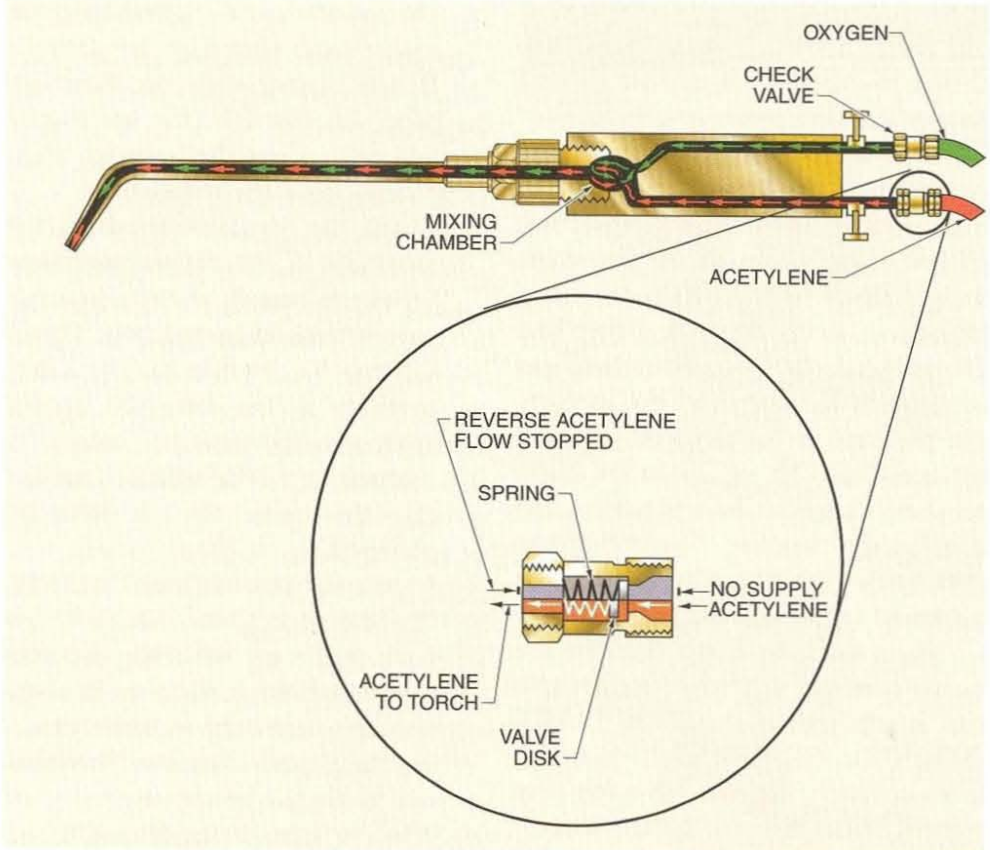
- Check the adjusting screw before the cylinder valve is turned ON and release it when welding has been completed.
- Never use oil on a regulator. Use only soap or glycerin to lubricate the adjusting screw.
- Do not attempt to interchange the oxygen and acetylene regulators.
- If a regulator does not function properly, shut OFF the gas supply and have a qualified service technician check the regulator.
- Check the regulator regularly for creeping. If the regulator creeps (does not remain at set pressure), have it repaired immediately. Creeping can be seen on the working-pressure gauge after the needle valves on the torch are closed. A creeping regulator usually requires that the valve seat or stem be changed.
- Check the mechanisms regularly. If the gauge pointer fails to go back to the pin when the pressure is released, the mechanism is likely sprung, caused by pressure entering the gauge suddenly. This condition should be repaired.
- Always keep a tight connection between the regulator and the cylinder. If the connection leaks after tightening, close the cylinder valve and remove the regulator. Clean both the inside of the cylinder valve seat and the regulator inlet-nipple seat. If the leak persists, the seat and threads are probably marred, and the regulator must be returned to the manufacturer for repair.

Check Valves

A *check valve* is a valve that allows the flow of liquid or gas in one direction only. See Figure 4-12. In welding apparatus, the pressure in the supply hose is higher than the pressure in the torch, allowing a valve disk in the check valve to open and release the gas into the torch. If the pressure in the torch becomes higher than that in the supply hose, such as when a flashback occurs, the valve disk closes, shutting OFF the supply of gas to the torch. A check valve must be positioned at the torch inlet, and can also be placed at the regulator outlet. The check valve must be replaced if a flashback occurs.

Do not lubricate the adjusting screw on a regulator with oil. Use soap or glycerin.

Figure 4-12. *A check valve is connected to the torch and the hose to ensure that oxygen and acetylene flow only toward the torch.*



Never interchange oxygen and acetylene hoses. Avoid dragging them over greasy floors.

Oxygen and Acetylene Hoses

A special nonporous hose is used for welding. To prevent the hoses from being misconnected, the oxygen hose is always green in color and the acetylene hose is red. Hoses must be properly marked because if oxygen were to pass through a hose that had previously contained acetylene, a dangerous combustible mixture might result.

A standard connection is used to attach the hose to the regulator and torch. The connection consists of a nipple that is forced into the hose and a nut that connects the nipple to the regulator and the torch. The acetylene nut can be distinguished from the oxygen nut by the notch that runs around the center, indicating a left-hand thread. See Figure 4-13. A clamp is used to squeeze the hose around the nipple to prevent it from working loose.

In the United States, green (oxygen) and red (acetylene) are the standard colors used for hoses. In Europe, blue is used for oxygen hoses and orange for acetylene hoses. Some parts of the world use black oxygen hoses.

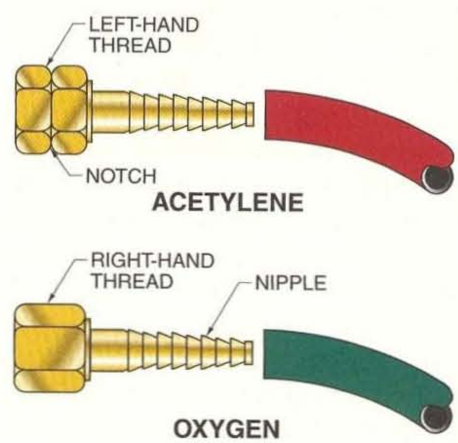


Figure 4-13. *The nut on the acetylene connection has a notch that runs around the center, distinguishing it from the nut on the oxygen connection.*

Care of Welding Hoses. All hose connections must be tight. The connections should be tightened with a close-fitting wrench to prevent damage to the nuts. Do not drag the hose across a greasy floor, as grease or oil can eventually soak into, and erode, the hose. The hose should not be pulled around sharp objects or across hot metal, and should be positioned so that it cannot be stepped on or damaged. When welding has been completed, the hose should be rolled up and suspended so that it will not drop to the floor. Also note these additional precautions:

- All new hose is dusted with talcum powder inside. The powder should be blown out with dry air before first use.
- Long lengths of hose tend to kink. Use the shortest length of hose to properly service the shop.
- Do not try to repair a leaking hose, replace it with a new hose assembly.

Sparklighters

A sparklighter, or striker, is a tool used for igniting the torch. See Figure 4-14. A sparklighter should always be used to light a torch. Never use matches or lighters to light a torch because the puff of the flame produced by the ignition of the acetylene flowing from the tip is likely to burn the skin.

ESAB Welding and Cutting Products

Figure 4-14. *A sparklighter is used for lighting a torch.*

Goggles

An oxyacetylene flame produces intense light and heat rays that may destroy eye tissue if the eyes are not properly shielded. Goggles that have a suitable approved colored glass should always be worn. The density of the colored lenses should be such that damaging light and heat rays are not allowed to pass through to the welder.

For most oxyfuel welding, goggles with shade numbers of 4, 5, and 6 are recommended. Goggles also protect the eyes from flying sparks and pieces of molten metal (spatter). See Figure 4-15. The American Welding Society (AWS) produces standards for eye protection that have additional information on the correct shielding for each welding operation.

Wear proper goggles and other personal protective equipment.

Protective Clothing

An apron, shop coat, or coveralls should always be worn when welding with oxyacetylene equipment. Sparks commonly shoot away from the molten metal and, unless suitable covering is worn, will burn holes in clothes. Sparks that burn through clothes may also burn the skin. Under no circumstances should flammable garments be worn when welding. A small spark that falls on flammable garments may burst into a rapidly spreading flame. A welding cap should also be worn to prevent hot metal particles from falling on the hair.

Never light a torch with a match or a lighter.

A pair of lightweight gloves should be worn to prevent burns. Occasionally the hot end of filler metal or a piece of metal that has been set down to cool is picked up by mistake, and without gloves, serious burns may result.

OTHER WELDING GASES

Although acetylene is commonly used for certain types of welding, other gases may be used. The most common of these are methylacetylene-propadiene stabilized, more commonly known as MAPP gas, and hydrogen. The principal difference between these gases and acetylene is in the properties of the gas used in the burning mixture; the welding technique is the same.

Never use air blown through the torch to blow dirt and dust from clothing.

Figure 4-15. *Goggles with the recommended shade number should always be worn during welding.*

TYPE OF GAS WELDING	PLATE THICKNESS	SHADE NUMBER
Gas Welding		
Light	less than ⅛″	4 or 5
Medium	⅛″ to ½″	5 or 6
Heavy	over ½″	6 or 8
Oxygen Cutting		
Light	less than 1″	3 or 4
Medium	1″ to 6″	4 or 5
Heavy	over 6″	5 or 6

MAPP Gas

Acetylene produces a very high flame temperature but is very unstable. MAPP gas has many of the physical properties of acetylene, but lacks the shock sensitivity of acetylene. MAPP gas is the result of a rearrangement of the molecular structures of acetylene and propane. When the two gases are combined, their molecular structure is changed and a very stable fuel results, with a flame temperature nearly comparable to acetylene.

Although propane itself is very stable, its low flame temperature limits its capabilities for welding. MAPP gases can be used for welding if the fuel-to-oxygen ratio is increased to raise the temperature of the flame. Deoxidized filler metal must also be used to ensure a sound weld when using MAPP gas for welding.

Generally, a slightly larger welding tip is required with MAPP gas because of its greater gas density and slower flame propagation rate. The only significant difference is in the flame appearance. A neutral flame for welding will have a longer inner cone than with oxyacetylene gas.

Since MAPP gas is not sensitive to shock, it can be stored and shipped in lighter cylinders. Because acetylene must be stored in cylinders filled with a porous filler material saturated with acetone, empty acetylene cylinders weigh about 220 lb. Empty MAPP cylinders weigh only 50 lb. Normally, a filled cylinder of acetylene weighs 240 lb while a filled cylinder of MAPP gas weighs 120 lb.

Hydrogen

The combination of oxygen and hydrogen generates a low-temperature flame used primarily for welding thin sections of metal, usually aluminum, on which low temperatures are required. One of the unusual characteristics of an oxyhydrogen flame is that the flame is practically nonluminous. Consequently, it is often difficult to adjust for a neutral flame. To avoid welding with an oxidizing flame, the regulator should be adjusted for an accurate hydrogen flow before adjusting the oxygen. Oxyhydrogen welding is commonly used for underwater welding as it can be used at higher pressures than acetylene.

POINTS TO REMEMBER

1. Handle oxygen and acetylene cylinders with care. Never expose them to excessive heat and prevent contact with oil and grease.
2. Always hang up a torch when not in use to prevent it from dropping to the floor and being bent or damaged.
3. Be sure the adjusting screw on a regulator is fully released before opening a cylinder valve.
4. Do not lubricate the adjusting screw on a regulator with oil. Use soap or glycerin.
5. Never interchange oxygen and acetylene hoses. Avoid dragging them over greasy floors.
6. Wear proper goggles and other personal protective equipment.
7. Never light a torch with a match or a lighter.
8. Never use air blown through the torch to blow dirt and dust from clothing.

QUESTIONS FOR STUDY AND DISCUSSION

1. What safety devices are used to prevent cylinders from exploding when subjected to intense pressure?
2. What is the purpose of the protector cap on a cylinder?
3. How much should the cylinder valve be opened on an acetylene cylinder? On the oxygen cylinder?
4. Why is it dangerous to allow grease or oil to come in contact with the oxygen cylinder valve?
5. What is the function of the needle valves on a welding torch?
6. Why are the oxygen and acetylene hose fittings made with different screw threads?
7. How is the size of a welding tip indicated?
8. What could happen if pliers are used when removing welding tips?
9. What is a tip cleaner? When and why should it be used?
10. What is a two-stage pressure regulator?
11. What precautions should be observed in handling a pressure regulator?
12. Why is it dangerous to light a torch with a match or a lighter?
13. What are the advantages and disadvantages of using MAPP gas?
14. Hydrogen is often used instead of acetylene for what operation?
15. What welding goggle shade numbers are commonly used for most oxyacetylene welding?
16. What type of protective clothing is commonly worn when oxyacetylene welding?
17. Name three ways of distinguishing oxygen hoses from acetylene hoses. Name three ways of distinguishing oxygen fittings from acetylene fittings.
18. Who is responsible for repairing a damaged regulator?
19. How are oxygen and acetylene cylinders moved safely?

OAW– Setup & Operation

5

Oxyacetylene Welding (OAW)

The welding apparatus must be correctly assembled by the welder to ensure safe operation. A certain sequence must be followed in assembling the welding apparatus to ensure a proper and safe connection. Once the apparatus is assembled, the torch can be lit and adjusted for the required welding pressure.

Oxygen and acetylene cylinders must be safely stored when not in use. When stored, cylinders must be chained in an upright position, with the oxygen cylinders separated from the acetylene cylinders. When in use, cylinders can be secured on a hand truck, chained to a secure object such as a bench in the shop, or secured in position adjacent to a manifold system.

WELDING APPARATUS ASSEMBLY

Before assembling the welding apparatus, cylinders must be securely fastened to a hand truck or some fixed object where they are to be located. Remove the protector cap from each cylinder and examine the outlet nozzles closely. Make sure the connection seat and screw threads are not damaged. A damaged screw thread may ruin the regulator nut, while a poor connection seat causes the gas to leak. See Figure 5-1. To assemble a welding apparatus follow the procedure:

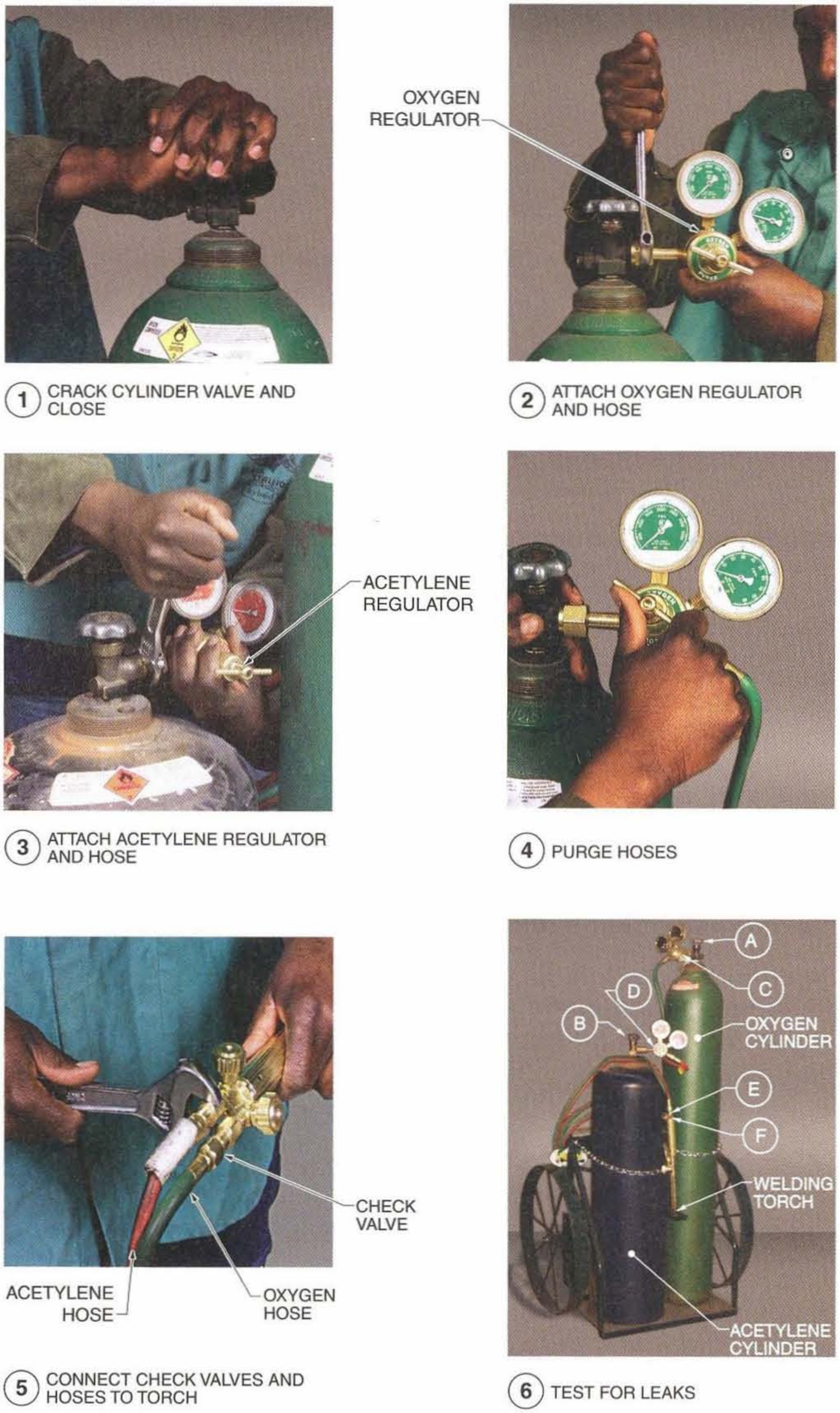
1. Crack the cylinder valves to remove foreign matter. Particles of dirt can collect in the outlet nozzle of the cylinder valve. Wipe out the connection seat with a clean cloth. If not cleaned out, the dirt can work into the regulator when the pressure is turned ON.
2. Connect oxygen regulator and hose. Connect the oxygen regulator to the oxygen cylinder and the oxygen hose to the oxygen regulator. Use a wrench to tighten the nuts and avoid stripping the threads. Always use the proper size wrench to tighten the nuts; a loose-fitting wrench will eventually wear the corners of the regulator nuts.
3. Connect the acetylene regulator and hose. Connect the acetylene regulator to the acetylene cylinder and the acetylene hose to the acetylene regulator.
4. Purge hoses. Check the adjusting screw on each regulator to ensure that it is released, then open the cylinder valves. Blow out any dirt that may be lodged in the hoses by opening the regulator adjusting screws. Opening the adjusting screws slightly will also purge the hoses of any residual gases. Promptly close the regulator adjusting screws.
5. Connect check valves and hoses to torch. To prevent the reverse flow of gases that would result in a combustible mixture in the welding hose, check valves are mounted to the welding torch. Under normal conditions, gases flow toward the welding torch.

Cylinders must be properly secured to prevent damage and possible injury.

Figure 5-1. *The welding apparatus must be properly assembled to ensure proper and safe operation during welding.*

Point the valve outlet nozzle away before cracking the cylinder.

Welding Apparatus Assembly
Figure 5-1



Any condition that might cause a reverse flow of gas will close the valve. Check valves should be left in place on the torch when the hose is detached.

Connect the hoses to the check valves mounted on the torch. The red hose is connected to the acetylene check valve mounted on the needle valve fitting marked AC. The green hose is connected to the check valve mounted on the needle valve fitting marked OX. Acetylene hose connections always have left-hand threads as indicated by the notched nut, and oxygen hose connections have right-hand threads.

6. Test for leaks. All new welding apparatus must be tested for leaks before being operated. It is advisable to periodically test apparatus in service to ensure that no leakage has developed. A leaky apparatus is very dangerous as leaking gas may be exposed to a spark and develop into a fire. Additionally, leaks mean that gas is wasted.

To test for leaks, open the oxygen and acetylene cylinder valves and, with the needle valves on the torch closed, adjust the regulators to approximately normal working pressure. Apply soapy water with a brush on the following points:

A—Oxygen cylinder valve
B—Acetylene cylinder valve
C—Oxygen regulator inlet connection
D—Acetylene regulator inlet connection
E—Hose connections at the regulators and torch
F—Oxygen and acetylene needle valves

Inspect each point carefully. Any noises, such as a hissing sound or bubbles, are an indication of leakage. If a leak is detected at a connection, use a wrench to properly tighten the fitting. If tightening does not remedy the leak, shut the gas pressure OFF, open the connections, and examine the screw threads.

To check for leakage in the welding hose, adjust the regulators to working pressure. Submerge the hose in clean, clear water. Check for any bubbles indicating a leak. On sections of welding hose that cannot be submerged, brush on soapy water and check for bubbles. Welding hoses should be routinely inspected for cuts and worn areas that could eventually leak.

Periodically test the welding apparatus for leaks. Use soapy water only.

Using the correct size welding tip provides sufficient heat to melt the base metal for the required welding process.

Selecting Welding Tips

The size of the welding tip used depends on the thickness of metal to be welded. If very light sheet metal is to be welded, a tip with a small opening is used, while a large-sized tip is needed for thick metal.

A numbering system is used to identify tip sizes. The number system ranges from 000 to 15, with the most common tip sizes between 000 and 10. See Figure 5-2. With this system, the higher the number, the larger the tip diameter.

The correct welding tip must be used with the proper working pressure. If too small a tip is used, the heat will not be sufficient to fuse the metal to the proper depth. When the welding tip is too large, the heat is too great and burns holes in the metal.

The welding tip size is determined by the thickness of metal welded.

⚠ CAUTION

If there is a suspected leak in a cylinder, move the cylinder out-of-doors away from possible sources of ignition and notify the supplier immediately.

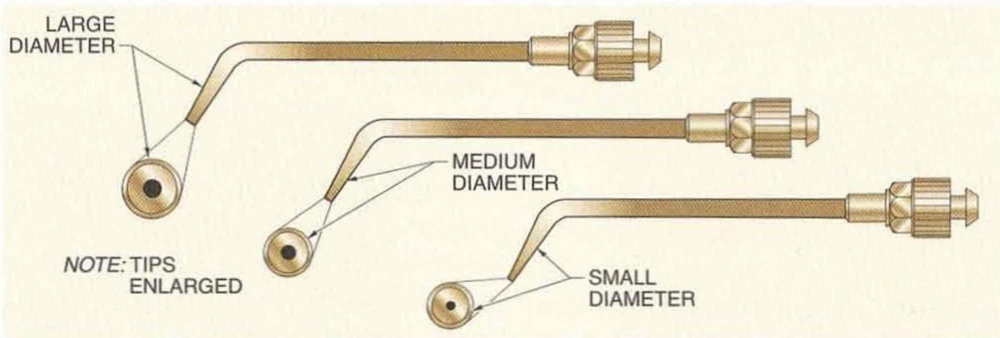


Figure 5-2. *The size of the welding tip is determined by the thickness of metal welded. The proper tip size and working pressure must be selected to provide a quality weld.*

COMMON WELDING TIP SIZES

Tip Number	000	00	0	1	2	3	4	5	6	7	8	9	10
Thickness of Metal*	up to 1⁄64	1⁄64	1⁄32	1⁄16	3⁄32	1⁄8	3⁄16	1⁄4	5⁄16	3⁄8	1⁄2	5⁄8	3⁄4 and up
Oxygen Pressure†	1	1	1	1	2	3	4	5	6	7	7	7½	9
Acetylene Pressure†	1	1	1	1	2	3	4	5	6	7	7	7½	9

* in in.
† in psi

A satisfactory weld must have the right amount of penetration and smooth, even, overlapping ripples. Unless conditions are optimized, it is impossible for the torch to function the way it should, and a poor weld will result. Ensure that the apparatus, including the hoses, regulators, check valves, torch, and welding tip are properly connected before lighting the torch.

Lighting Torches

1. Select the correct welding tip size for the metal to be welded and connect it to the torch.
2. Stand to one side and open the oxygen and acetylene cylinder valves slowly. See Figure 5-3. Open the acetylene cylinder valve approximately one complete turn and open the oxygen valve all the way. Do not face the regulator when opening the cylinder valve. Oxygen and acetylene are stored under high pressure. If the gas is permitted to come against the regulator suddenly, it may cause damage to the equipment. In addition, a defect in the regulator may cause the gas to blow through, shattering the glass and causing injury to the welder.

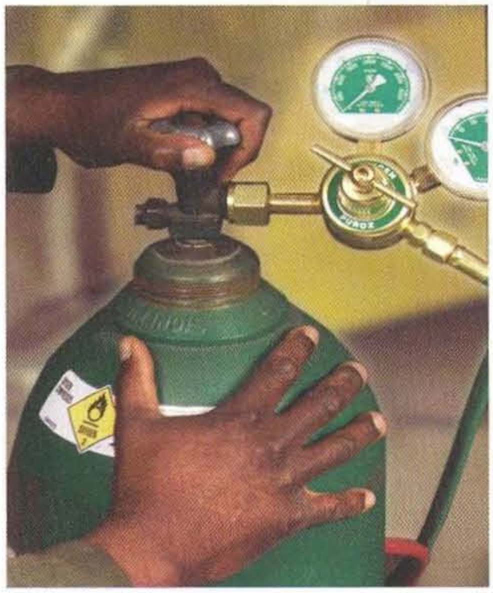


Figure 5-3. *Stand to one side of the regulator when opening a cylinder valve.*

3. Set the working pressure of the oxygen and acetylene regulator adjusting valves to correspond to the required working pressure of the welding tip being used.
4. Turn the acetylene needle valve on the torch approximately one-half turn.
5. With the sparklighter held about 1″ away from the end of the welding tip, ignite the acetylene as it leaves the tip. Adjust the acetylene until the smoke disappears. See Figure 5-4.

Stand to one side before opening a cylinder valve and be sure the regulator adjusting screw is fully released.

When igniting a torch, keep the tip of the torch facing downward. Lighting the torch while it is facing outward or upward could cause injury to workers nearby.

Figure 5-4. *Hold the sparklighter approximately 1″ from the tip when lighting the torch.*

Adjusting the Welding Flame

With the acetylene ignited, gradually open the oxygen needle valve until a well-defined white cone appears near the tip surrounded by a second, bluish cone that is faintly luminous. This is known as a neutral flame because there is an approximate one-to-one mixture of acetylene and oxygen, which results in a flame that is chemically neutral. A *neutral flame* is a flame that has neither oxidizing nor carburizing characteristics. The brilliant white cone should be approximately $\frac{1}{16}''$ to $\frac{3}{4}''$ long, depending on the welding tip size. See Figure 5-5. A neutral flame is used for most welding operations.

Any variation from the one-to-one oxygen-acetylene mixture will alter the flame characteristics. When excess oxygen is forced into the oxyacetylene mixture, the resulting flame is said to be oxidizing. An *oxidizing flame* is a flame in which there is an excess of oxygen. The oxygen-rich zone extends around and beyond the cone. An oxidizing flame resembles the neutral flame slightly, but has an inner cone that is shorter and more pointed with an almost purple color rather than brilliant white. It is sometimes used for brazing.

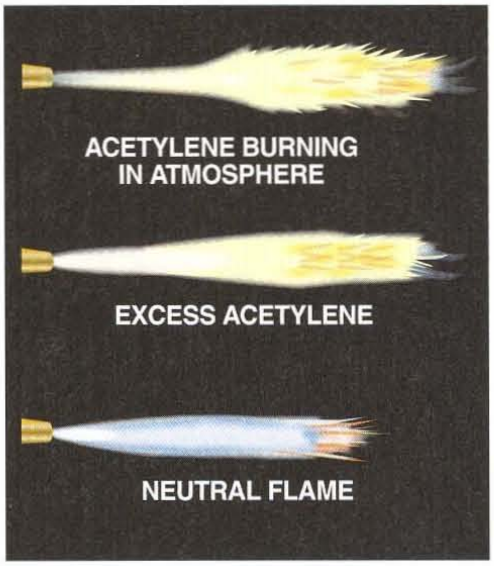


Figure 5-5. *With the acetylene burning, gradually open the oxygen needle valve to obtain a neutral flame.*

If the oxyacetylene mixture consists of a slight excess of acetylene, the flame is carburizing, or reducing. A *carburizing flame* is a reducing flame in which there is an excess of fuel gas. The carbon-rich zone extends around and beyond the cone. This flame can be easily identified by the existence of three flame zones instead of the usual two found in the neutral flame. The end of the brilliant white cone is no longer as well defined, and it is surrounded by an intermediate white cone, which has a feathery edge in addition to the usual bluish outer envelope. See Figure 5-6.

⚠ WARNING

Never use a match to light a torch. This procedure brings the fingers too close to the tip and the sudden ignition of the acetylene is likely to burn them.

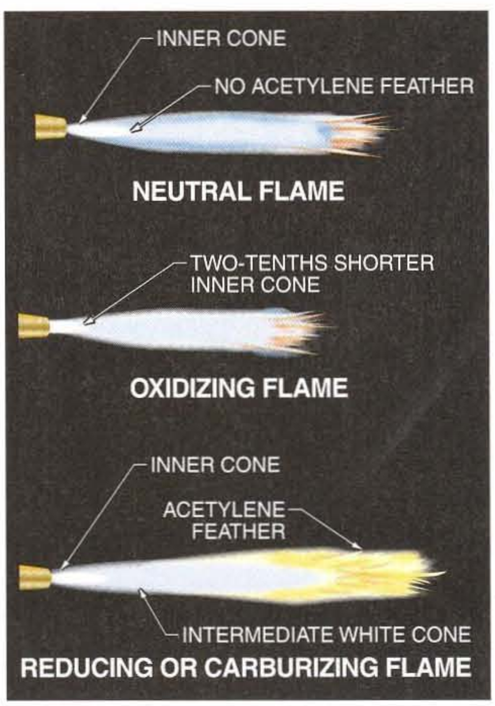


Figure 5-6. *An oxidizing flame is the result of an excess of oxygen in the mixture. A slight excess of acetylene produces a carburizing flame.*

Adjust the torch to a soft, neutral flame for welding unless the type of metal being welded requires a different type of flame.

Prevent conditions that may cause a backfire or flashback.

Keep the passage in the welding tip clean and flowing freely.

Flame Characteristics. A flame may be harsh or quiet. A harsh flame is produced by too much pressure of both gases to the welding tip. A harsh flame is undesirable, since it has a tendency to depress the molten surface and cause the metal to spatter around the edges of the weld pool. A harsh flame is noisy and makes it extremely difficult to achieve complete fusion with smooth, uniform ripples.

A quiet flame is just the opposite of a harsh flame and is achieved by the correct pressure of gases flowing to the tip. The flame is not a harsh, noisy flame but one that permits a continuous flow of the weld pool without any undue spatter.

To ensure a soft, quiet, neutral flame, the welding tip must be clean and the correct oxyacetylene mixture used. Even with the proper proportion of acetylene and oxygen, a good weld is difficult to achieve unless the opening in the tip allows a free flow of gases. Any foreign matter in the welding tip restricts the heat necessary to melt the metal.

Flame Control. As welding progresses, the flame cone should be observed to ensure that the mixture remains consistent. Changes in the flame occur as a result of slight fluctuations in the flow of the gases from the regulators. A slight adjustment to either the oxygen or the acetylene will readjust the flame.

During welding, the torch may occasionally "pop." Popping is an indication that there is an insufficient amount of gases flowing to the welding tip. Popping can be stopped by further opening both the oxygen and acetylene needle valves on the torch. Another cause of popping is overheating of the weld pool by lingering, or keeping the flame too long in one position and not melting enough filler metal into the weld pool.

Backfire and Flashback. When the flame goes out with a loud pop, it is called a backfire. A *backfire* is a quick recession of the flame into the welding tip, typically followed by extinction of the flame.

A backfire may be caused by operating the torch at lower pressures than required for the welding tip used; touching the welding tip against the work; overheating the welding tip; or by an obstruction in the welding tip. If a backfire occurs, shut the needle valves and, after remedying the cause, relight the torch.

A *flashback* is a recession of the flame into or back of the mixing chamber in a flame torch or flame spray torch. A flashback flashes quickly into the torch and burns inside with a shrill hissing or squealing noise. If a flashback occurs, close the needle valves immediately. A flashback generally is an indication that something is wrong. A welding tip may be clogged, the needle valves may be functioning improperly, or the acetylene or oxygen pressure may be incorrect. The malfunction must be corrected and damaged equipment replaced before relighting the torch.

Shutting Off Torches

When welding is completed, the torch must be properly shut off. After the torch is shut off, it must be stored properly. The hoses must be removed from the cylinders and hung out of the way. Protector caps must be screwed onto the cylinders to protect the handwheels and valves. Cylinders must be chained and stored safely. Following is the correct sequence of steps for shutting off a torch:

1. Close the oxygen needle valve.
2. Close the acetylene needle valve.
3. If the entire welding unit is to be shut down, shut off both the acetylene and the oxygen cylinder valves.
4. Open the needle valves until the lines are drained to remove pressure from the working pressure gauges. Then promptly close the needle valves.
5. Release the adjusting screws on the pressure regulators.

POINTS TO REMEMBER

1. Cylinders must be properly secured to prevent damage and possible injury.
2. Point the valve outlet nozzle away before cracking the cylinder.
3. Periodically test the welding apparatus for leaks. Use soapy water only.
4. The welding tip size is determined by the thickness of metal welded.
5. Stand to one side before opening a cylinder valve and be sure the regulator adjusting screw is fully released.
6. Adjust the torch to a soft, neutral flame for welding unless the type of metal being welded requires a different type of flame.
7. Prevent conditions that may cause a backfire or flashback.
8. Keep the passage in the welding tip clean and flowing freely.

Exercises

Testing the Flames

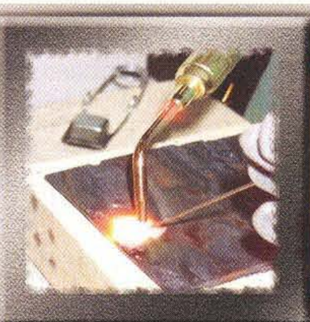
exercise 1

The characteristics of the carburizing and oxidizing flames must be understood for correct adjustment of the neutral flame. To become familiar with the effects of the various flames, complete the following exercise:

1. Obtain a piece of scrap metal. Light the acetylene and turn on the oxygen until a white cone appears on the end of the welding tip enveloped by another fan-shaped cone that has a feathered edge.
2. While wearing goggles, apply the carburizing flame to the metal, holding the point of the white cone close to the metal. Notice that as the metal melts, it has a tendency to boil. This is an indication that carbon is entering the molten metal. After the metal has cooled, the surface will be pitted and very brittle.
3. Open the oxygen needle valve completely. The white cone becomes short and the color changes to a purplish hue. The flame burns with a roar.
4. Apply the oxidizing flame to the piece of metal, allowing the cone to come in contact with the surface. As the metal melts, numerous sparks are given off and a white foam forms on the surface. After the piece cools, the metal will be shiny.
5. Adjust the needle valve until the flame is balanced. Apply the neutral flame to the piece of metal. The molten metal flows smoothly, with very few sparks.

QUESTIONS FOR STUDY AND DISCUSSION

1. Why should cylinders be securely fastened before being used?
2. Why should the cylinder outlet nozzles be examined closely?
3. What is the proper order for setting up the welding apparatus?
4. Why are check valves used?
5. What is the proper method of testing for gas leaks?
6. What governs the size of the welding tip that should be used?
7. Describe the process for lighting and adjusting the flame for a cutting torch.
8. How far should the acetylene needle valve be opened when lighting the torch?
9. What is an oxidizing flame?
10. What is a carburizing flame?
11. What is the difference between a neutral flame and a carburizing flame?
12. What are the characteristics of a neutral flame?
13. What is the difference between a harsh flame and a quiet flame?
14. What are some of the conditions that may cause a backfire?
15. What is meant by a flashback when one is using an oxyacetylene torch?
16. Why are hoses purged after being connected to the regulators?
17. Why should the welder stand to one side when opening cylinder valves?
18. What is the last step done to the regulator when shutting off the torch?
19. What kind of mixture of oxygen and acetylene is required to achieve a neutral flame?
20. What happens when an oxidizing flame is used to melt the metal?



OAW–Flat Position

6

Oxyacetylene Welding (OAW)

Welding with an oxyacetylene torch requires practicing a series of operations in a prescribed order. These operations involve carrying a weld pool, depositing a weld bead with filler metal, and welding various types of joints. In flat position welding, the torch and filler metal are held with the weld joint in the flat position.

CARRYING A WELD POOL

Before performing welding operations, beginning welders should learn the proper technique for forming and maintaining a uniform weld bead. A consistent weld bead can be formed and maintained using an oxyacetylene torch to create and carry a weld pool. The weld pool must be carried along the joint at a consistent width and depth. How the torch is held, the torch position in relation to the joint, and the motion used to carry the weld pool have a direct effect on the quality of the weld bead.

Holding the Torch

A torch should be held like a hammer, with the fingers lightly curled underneath the torch. See Figure 6-1. To prevent fatigue, the torch should balance easily in the hand.

Figure 6-1. *When welding light-gauge metal in flat position, grasp the torch like a hammer.*

Positioning and Moving the Torch

The torch should be held so that the flame points in the direction of welding and at an angle of about 45° to the weld joint. If right-handed, start the weld at the right edge of the metal. The left-handed welder should start welding at the left edge of the metal, working in the reverse direction. See Figure 6-2.

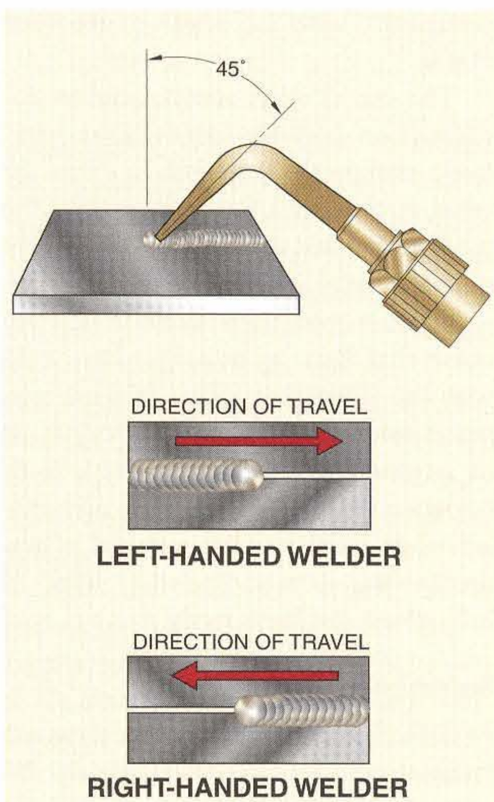


Figure 6-2. *To move the weld pool across the workpiece, hold the torch at a 45° angle and manipulate it in a circular motion.*

Move the torch just fast enough to keep the weld pool active and flowing forward.

Use filler metal with a diameter equal to the thickness of the base metal.

Bring the inner cone of the neutral flame to within 1/8" of the surface of the workpiece. Hold the torch still until a molten weld pool forms, then move the weld pool across the workpiece. As the weld pool travels forward, rotate the torch in a circular pattern to form a series of overlapping ovals.

Do not move the torch ahead of the weld pool, but slowly work forward, giving the heat a chance to melt the metal. If the flame is moved forward too rapidly, the heat fails to penetrate far enough into the metal and the metal does not melt sufficiently. If the torch is kept in one position too long, the flame will burn a hole through the metal.

ADDING FILLER METAL

On some joints, it is possible to weld two workpieces without adding filler metal. For most welding jobs, however, filler metal is advisable because it builds up the weld, adding strength to the joint. The strength of a weld depends largely on the skill with which the filler metal is blended, or interfused, with the edges of the base metal.

The use of filler metal requires coordination of both hands. One hand must manipulate the torch to carry the weld pool across the plate, while the other hand must add the correct amount of filler metal.

Some welding applications may require that flux be added to the weld with the filler metal. *Flux* is a material that hinders or prevents the formation of oxides and other undesirable substances in molten metal. Flux also dissolves or facilitates the removal of undesirable substances and is used to help clean the base metal.

Selecting Filler Metal

A welded joint should possess as much strength as the base metal itself. To achieve the required strength, it is necessary to use filler metal that has the same properties as the base metal. Inferior filler metals may contain impurities that make them difficult to use and that create a weak or brittle weld. A good filler metal flows smoothly and readily unites with the base metal without excessive sparking.

A poor quality filler metal sparks profusely, flows irregularly, and leaves a rough surface filled with punctures, like pinholes.

Filler metals come in a variety of sizes ranging from 1/16" to 3/8" in diameter. The size filler metal to use depends largely on the thickness of the base metal. The general rule is to use filler metal with a diameter equal to the thickness of the base metal. For example, if a 1/16" thick metal is to be welded, a 1/16" diameter filler metal should be used.

Many types of filler metal are available for welding a variety of metals. For example, a mild (low-carbon) steel filler metal is used to weld cast iron, a nickel filler metal for nickel steel, a bronze filler metal for bronzing malleable cast iron and other dissimilar metals, an aluminum filler metal for aluminum welding, or a copper filler metal for copper products.

Manipulating Filler Metal

Hold the filler metal at approximately the same angle as the torch but slanted away from the torch. The filler metal should be moved at a consistent rate and speed as it is fed into the weld pool. See Figure 6-3.

Figure 6-3. *Hold the torch and filler metal at the same angle and maintain a consistent travel angle and feed speed when adding filler metal to the weld.*

Melt a small pool of the base metal and then insert the tip of the filler metal into the weld pool. To ensure proper fusion, the correct diameter filler metal must be used.

If the filler metal is too large, the heat of the weld pool will be insufficient to melt it. If the filler metal is too small, the heat of the weld pool cannot be absorbed by the filler metal, and a hole will be burned in the workpiece.

As the filler metal melts in the weld pool, advance the torch forward. Concentrate the flame on the base metal and not on the filler metal. Do not hold the filler metal above the weld pool, as the molten metal will have to drip down to the weld pool. When molten metal falls, it combines with the oxygen of the air and part of it burns up, causing a weak, porous weld. Always dip the filler metal in the center of the weld pool.

A beginning welder may have trouble holding the filler metal steady, which can cause the filler metal to stick to the base metal. Instead of inserting the filler metal in the middle of the weld pool where the heat is sufficient to melt it readily, the beginning welder may insert it near the edge of the weld pool where the temperature is lower. However, the heat at the edge may not be hot enough to melt the filler metal. If the filler metal is not melted sufficiently it may stick to the weld. Do not try to jerk filler metal loose, since such an action will simply interrupt the welding. Instead, to loosen the filler metal, play the flame directly on the tip and the filler metal will be loosened. While the filler metal is being freed, the weld pool will likely solidify; therefore, the weld pool must be re-formed before moving forward.

Depositing Weld Beads

Rotate the torch to form overlapping ovals, and keep raising and lowering the filler metal as the weld pool is moved forward. Advance the weld pool about 1/16″ with each complete motion of the torch. An alternate torch movement is a semicircular motion. See Figure 6-4. When the filler metal is not in the weld pool, keep the tip just inside the outer envelope of the flame.

Torch Movement Patterns
Figure 6-4

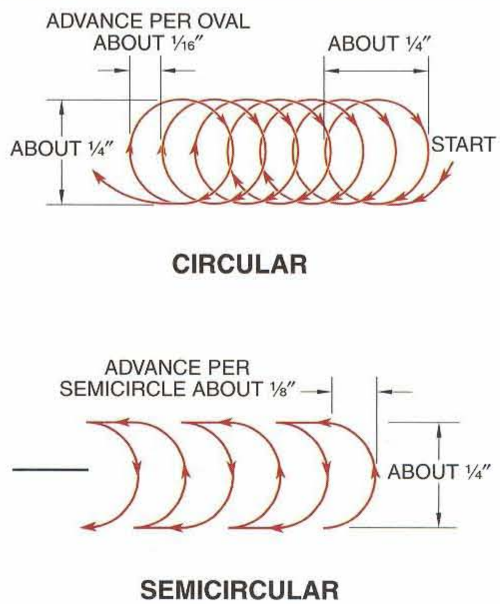


Figure 6-4. *The torch can be moved in a circular or semicircular motion when depositing beads in flat position.*

Do not hold the filler metal so high above the weld pool that the molten metal drips onto the weld pool.

Maintaining Travel Speed. To secure weld beads of uniform width and height, keep the forward movement of the torch consistent. If the travel speed is too slow, the weld pool is carried forward too slowly, it becomes too large, and may burn through the metal. If the travel speed is too rapid, the filler metal does not fuse thoroughly with the base metal but merely sticks on the surface. It will also be impossible to form even ripples.

When the weld pool appears to be getting too large, withdraw the flame slightly so that only the outer envelope of the flame is touching the weld pool. Do not move the flame to one side, since such a movement allows air to strike the hot metal, oxidizing the metal.

When welding with filler metal, move the torch in a semicircular or circular motion.

WELDING BUTT JOINTS

Once the task of carrying a weld pool across the surface of a workpiece while adding filler metal is mastered, the next task is to fuse two workpieces together using a butt joint.

Tack Welds

Workpieces must be tacked at regular intervals before welding to maintain the root opening. See Figure 6-5. To make a tack weld, apply the flame to the workpiece until it melts and then add filler metal.

Progressive spacing may be used to allow for closing of the root opening. Progressive spacing between the edges of a seam is not commonly used, but if it is specified, allow a gap of about 1/16″ at the starting end of the joint and approximately 1/8″ at the other end. The space permits the flame to melt the edges all the way through to the bottom of the workpieces, allowing for complete fusion.

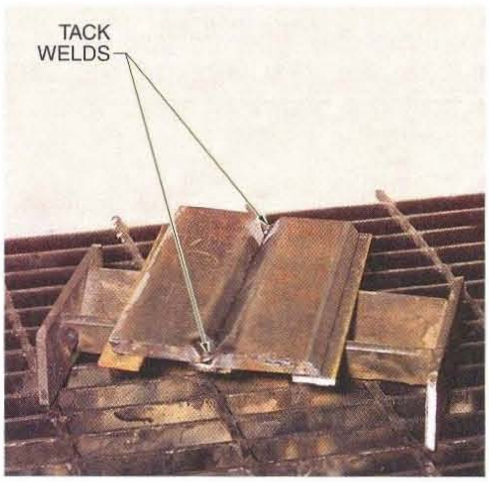


Figure 6-5. *Tack welds restrict expansion forces in metal that is to be welded.*

Butt Joint Defects

The first few welds a beginning welder makes may easily break. A beginning welder should practice until a straight, smooth weld that does not open when bent can be made. Some common defects that may occur when first learning to weld are:

When using progressive spacing, allow a space between workpieces to compensate for expansion forces.

- holes in the joint, caused by holding the flame too long in one spot
- a brittle weld, resulting from improper flame adjustment during welding or dripping filler metal
- excessive metal hanging underneath the weld, as the result of too much penetration caused by moving the torch forward too slowly
- insufficient penetration, caused by moving the torch forward too rapidly

When penetration is correct, the underside of the seam should show that fusion has taken place completely through the joint. See Figure 6-6.

Penetration of Filler Metal
Figure 6-6

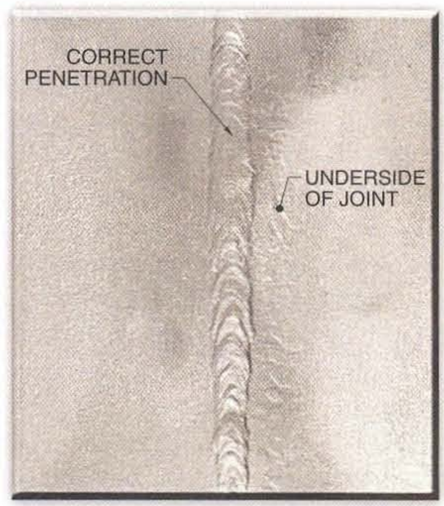


Figure 6-6. *When penetration is correct, complete fusion is evident on the underside of the joint.*

- hole in the end of the joint, caused by not lifting the torch when the end of the weld has been reached
- uneven weld bead, caused by moving the torch too slowly or too rapidly

Often, a joint appears to have the correct penetration but still cracks open when tested. Cracks may be caused by one of several problems, such as:

- improper space allowances between the edges of the workpieces
- filling the space between the workpieces with molten filler metal without sufficiently melting the edges of the workpieces, which

results in a poor bond between the base metal and the filler metal
- holding the torch too flat, causing the weld pool to lap over an area that has not been properly melted

WELDING OTHER JOINTS

When the ability to weld a correct butt joint is mastered, other joints may be welded using techniques similar to those used on the butt joint. A flange joint is used a great deal in sheet metal work, particularly on material that is 20 gauge or less. The flange portion should extend above the surface of the sheet a distance roughly equal to the thickness of the sheet.

A corner joint is used extensively in fabricating products such as tanks and vessels, as well as in repair work. The edges are fused without filler metal, as in welding a flange joint.

A lap joint is formed when one piece of metal is laid on top of another. Careful control of the direction of heat is needed for a lap joint weld.

A T-joint is made by laying one workpiece flat and standing the other workpiece on top to form a T. The T-joint requires a greater amount of filler metal than other joints. Correct filler metal usage is critical.

OAW – CAST IRON

Gray cast iron may be welded; however, extreme caution must be taken to offset expansion and contraction forces. Since gray cast iron is brittle, it is susceptible to rapid temperature changes (thermal shock), making preheating and postheating necessary when welding cast iron.

To maintain the gray iron structure throughout the weld area, the weld must be made with the correct filler metal. All weld parts must be cooled slowly. If the casting is cooled too rapidly, the weld area is likely to turn into white cast iron, making the weld section extremely brittle and so hard that machining may be impossible.

Preparing Edges

The edges of the casting should be beveled to a 90° groove angle. The V should extend only to 1/8″ from the bottom of the break. Beveling makes it easier to build up a sound weld near the bottom and lessens the likelihood of melt-through. Placing carbon backing bars underneath the joint also helps to prevent the molten cast iron from running out the seam.

Precautions must be taken to clean the surfaces of the joint before welding. The weld area should be cleaned at least 1″ on both sides of the V or the joint if no groove is made in the metal. Improperly cleaned surfaces result in porosity in the weld, even if sufficient flux is used.

Preheating and Postheating

When welding cast iron, the entire casting must be preheated to a dull red. Uniform preheating equalizes expansion and contraction forces and minimizes the possibility of cracks. On a small section of cast iron, preheating can be carried out by playing the flame over the casting. A large casting may have to be placed in a preheating furnace. The temperature must be monitored carefully on a heavy casting, especially if it has thin members, to prevent overheating.

After welding is completed, postheat the cast iron by bringing the entire casting up to a uniform temperature. Use the same techniques as for preheating the casting.

Filler Metal and Flux

A cast iron filler metal that has the same composition as the base metal is used to weld cast iron. The cast iron filler metal contains silicon to ensure flowability. Correct preheating and postheating allow for machinability.

Using flux is also essential when welding cast iron to keep the weld pool fluid. Otherwise, infusible slag mixes with the iron oxide that forms on the

If possible, use carbon backing bars when welding cast iron.

Clean all welding surfaces at least 1″ around the seam that is to be welded.

Preheat cast iron to a dull red before welding.

Postheat cast iron after the weld is completed and then allow it to cool slowly.

weld pool. If infusible slag mixes with iron oxide, the weld will contain inclusions and porosity.

OAW – ALUMINUM

Although the gas shielded arc welding processes (GTAW and GMAW) are the most practical for welding commercially pure aluminum, oxyacetylene welding is occasionally used. If oxyacetylene welding must be used on aluminum, care must be taken not to overheat the aluminum, weakening the metal.

The following considerations must be kept in mind when welding aluminum with an oxyfuel process:

- Aluminum has a relatively low melting point compared to other metals. Pure aluminum melts at 1220°F (660°C).
- The thermal conductivity of aluminum is high—almost four times that of steel.
- Aluminum collapses suddenly into liquid when heated. Since it is light in color, there is practically no indication when the melting point is reached.
- Molten aluminum oxidizes very rapidly. A heavy coating forms on the surface of the seam, which necessitates the use of a good flux.
- Aluminum is very flimsy and weak when hot. Care must be taken to support it adequately during welding.
- Aluminum welds should be made in a single pass if possible.

⚠ CAUTION

The flame should never be permitted to come in contact with the weld pool.

Joint Designs

In general, the same principles of joint design for welding steel apply to aluminum. Aluminum from 1/16″ to 3/16″ thick can be welded using a butt joint, provided the edges are notched with a saw or chisel. Notching minimizes the possibility of burning holes through the joint, permits full penetration, and prevents local distortion. Permanent backings and fillet welded lap joints should not be used when welding aluminum as they may cause the flux to become entrapped in the weld, which leads to a greater likelihood of corrosion.

When welding heavy aluminum plate 3/16″ to 3/8″ thick, the edges should be beveled to form a 90° to 100° V. Allow a 1/16″ to 1/8″ notched root face. Aluminum that is greater than 3/8″ thick should be prepared as a double-V butt joint with a notched root face. The edges should be beveled to form a 100° to 120° V. See Figure 6-7.

As a rule, the lap joint is not recommended for aluminum welding because flux and oxide may become trapped between the surfaces of the joint, causing the aluminum to corrode.

Aluminum Joint Design
Figure 6-7

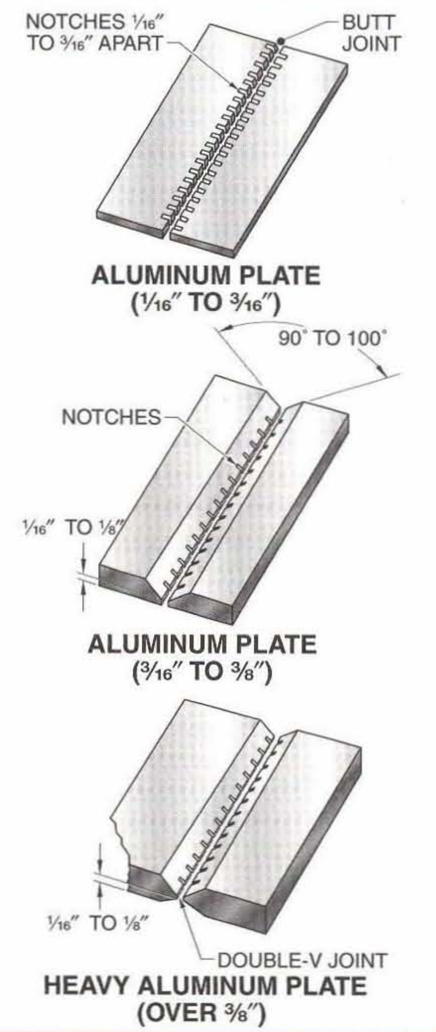


Figure 6-7. *Aluminum joint design is similar to that for most other metals. The angles, notches, and flanges are dependent on the thickness of the aluminum.*

Using Flux

The edges of aluminum to be welded must be thoroughly clean. All grease, oil, and dirt must be removed with an appropriate solvent or by rubbing the surface with steel wool or a wire brush.

Since aluminum oxidizes rapidly, a layer of flux must be used to ensure a sound weld. Flux is sold as a powder, which can be mixed with water to the consistency of a thin paste (approximately two parts flux to one part water). If filler metal is not required, the flux is applied to the joint by means of a brush.

When filler metal is used, it is coated with flux by first heating the filler metal and then dipping it into the flux.

On thick sections of metal, it is advisable to coat the base metal as well as the filler metal to ensure complete fusion. When welding is complete, all traces of flux must be washed away. Flux that remains on the weld can cause corrosion. Flux is removed by washing the workpiece in hot water or by immersing in a 10% cold solution of sulfuric acid, followed by rinsing in hot or cold water.

Selecting Filler Metal

The proper filler metal must be used when welding aluminum. The filler metal composition should be comparable to that of the aluminum to be welded. The three most common filler metals for welding nonheat-treatable aluminum are 1100, 4043, and 5356. The 4043 and the 5356 filler metals are recommended when greater strength is required.

Filler metals are available in 1/16″, 1/8″, 3/16″, and 1/4″ diameters. Generally, a filler metal whose diameter equals the thickness of the aluminum to be welded should be used.

Preheating. All aluminum to be welded, including thin sheet, should be preheated to minimize the effects of expansion and cracking. Aluminum 1/4″ thick or more should be preheated to a temperature of 300°F (149°C) to 500°F (260°C). Preheating to these temperatures can usually be done by playing the flame of the oxyacetylene torch over the work. For large or complicated parts, preheating is done in a furnace.

The preheating temperature must not exceed 500°F (260°C). If the temperature rises above 500°F, the alloy may be weakened or the aluminum may collapse under its own weight. The correct preheating temperature may be determined with a temperature-indicating crayon or by one of the following methods:

- A mark made on the metal with a carpenter's blue chalk will turn white.
- A pine stick rubbed on the metal will leave a char mark.
- No metallic ringing sound is heard if the metal is struck with a hammer.

Always use the recommended flux and filler metal when welding.

When welding aluminum, keep the preheat temperature below 500°F (260°C).

Selecting Torches

Since aluminum has high thermal conductivity, a welding tip slightly larger than one used for steel of the same thickness should be used. See Figure 6-8.

Many welders use hydrogen instead of acetylene when welding aluminum, and in many cases this is preferable, especially for welding light-gauge material. In either case, the torch should be adjusted to a neutral flame. Some authorities recommend a slightly reducing flame, but usually a neutral flame is satisfactory for producing a clean, sound weld. Whether using acetylene or hydrogen, the flame should be adjusted to a low gas velocity to permit a soft flame.

The torch angle has much to do with welding speed. Instead of lifting the flame from time to time to avoid melting holes in the metal, the welding torch should be held at a flatter angle to increase the welding speed. The welding speed should also be increased as the edge of the metal is approached.

When welding aluminum, use a slightly larger welding tip than is used for steel.

Use an 1100, 4043, or 5356 filler metal for welding aluminum.

Use a neutral or slightly reducing flame for all aluminum welding.

Figure 6-8. *Tip orifice diameter selection is based on the thickness of the aluminum to be welded.*

OXYACETYLENE WELDING DATA FOR ALUMINUM			
Aluminum Thickness*	Oxygen Pressure†	Acetylene Pressure†	Tip Orifice Diameter*
1/16	1+	.021 – .031	.030 – .0465
1/8	1 – 2	.025 – .038	.030 – .055
3/16	1 – 3	.031 – .0465	.0465 – .067
1/4	2 – 4	.038 – .055	.055 – .076
3/8	5 – 7	.067 – .086	.086 – .110
1/2	6 – 8	.076 – .098	.098 – .1285

* in in.
† in psi

Steel thicker than 1/8″ should be beveled before welding.

OAW – STEEL

Heavy steel is rarely welded with oxyacetylene unless other types of welding equipment are not available. Welding heavy steel with oxyacetylene is much slower and less cost-efficient than other methods. Occasionally, it may be necessary to use oxyacetylene welding to weld or repair a structure. When welding steel using OAW, maintain the proper oxygen and acetylene pressures. See Figure 6-9.

Single-V Butt Joints

Complete penetration of the weld is necessary to achieve maximum weld strength. On steel 1/8″ thick or less, complete penetration is reasonably easy to achieve. On thicknesses over 1/8″, penetration is not possible unless the edges are beveled. Edges can be beveled using a torch, a beveling machine, or a grinder.

When using a single-V bevel on steel, the groove angle should be 60°.

For steel up to 1/2″ thick, a single-V bevel is sufficient. A single-V bevel should have a groove angle of 60°. See Figure 6-10. The bottom of the V can have a 1/16″ or 1/8″ square root face (unbeveled) or have the edges feathered to a sharp point.

Some welding jobs require both edges of the joint to be beveled to form the 60° groove angle, single-V butt joint. More skill is required to weld a single-V butt joint in horizontal position because there is not a retaining shelf for the bead as there is on a single bevel butt joint.

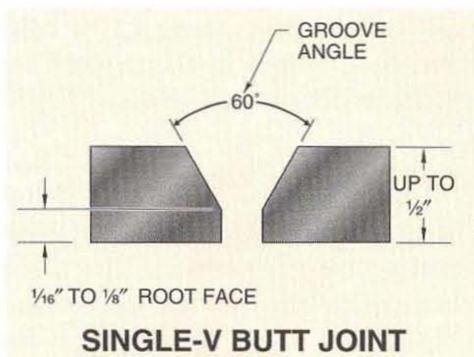


Figure 6-10. *A single-V butt joint is used for heavy steel up to 1/2″ thick, and requires a 60° groove angle.*

Figure 6-9. *When welding steel using OAW, maintain the proper oxygen and acetylene pressures.*

OXYACETYLENE WELDING DATA FOR STEEL			
Steel Thickness*	Oxygen Pressure†	Acetylene Pressure†	Tip Orifice Diameter*
1/8	2	2	.036
3/16	3	3	.043
5/16	4	4	.052
1/2	6	6	.073
3/4	7	7	.082
1	8	8	.094

* in in.
† in psi

The angle of the filler metal must be changed for each pass when welding a single-V butt joint. The number of passes depends on the thickness of the metal and the filler metal diameter. Sufficient penetration into each previous pass is necessary for complete fusion of the weld. On wide joints, the weld should be finished with a cover pass. A cover pass is made by using a wide weaving motion that covers the entire area of the deposited beads.

Double-V Butt Joints

On heavy steel ½″ thick or more, welds should be deposited on both sides of the joint. To deposit a weld on both sides, a double-V bevel is required. See Figure 6-11. A double-V bevel has a ¹⁄₁₆″ or ⅛″ root face. A 60° groove angle is also required.

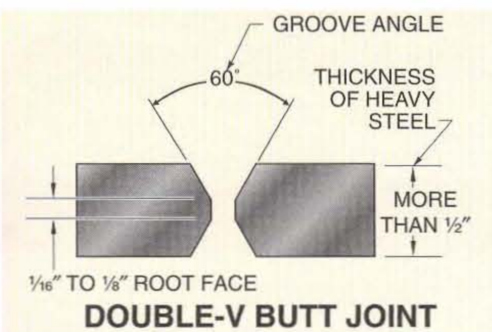


Figure 6-11. *A double-V butt joint is required when a weld must be deposited on both sides of a joint.*

When depositing a weld in a double-V joint, the weld should be built up in layers. It is difficult to control the weld pool and secure good penetration by trying to fill the V in one pass. Deposit one layer near the bottom of the V on both sides of the workpiece; then add successive layers to fill the V. Each successive pass must completely penetrate the previous passes and the sides of the base metal. The joint can be welded using forehand or backhand welding. *Forehand welding* is a welding technique in which the torch is directed toward the progress of welding.

Backhand Welding

Backhand welding is a welding technique in which the torch is directed opposite to the progress of welding. The backhand technique for welding heavy steel is similar to that used for thin metal; however, the problems associated with heavy steel welding are more complicated. In backhand welding, the weld is carried from left to right (or right to left for a left-handed person).

When welding on heavy steel, close attention must be paid to joint preparation and to the amount of heat required to ensure complete penetration. The flame is directed back toward the completed portion of the weld, and the filler metal is held between the flame and the completed weld section.

The flame is directed on the edges of the V ahead of the weld pool, so no sideways torch motion is necessary. A narrower V can be used with backhand welding than with forehand welding. The weld pool is less fluid in backhand welding, and the ripples are heavier and spaced further apart.

On steel ½″ thick or more, do not fill the V in a single pass. Use several passes.

When backhand welding, do not swing the torch; instead, move the filler metal.

A double-V joint must be used with steel ½″ thick or more.

POINTS TO REMEMBER

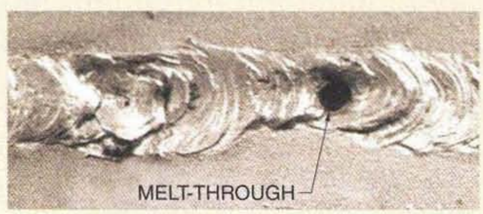
1. Move the torch just fast enough to keep the weld pool active and flowing forward.
2. Use filler metal with a diameter equal to the thickness of the base metal.
3. Do not hold the filler metal so high above the weld pool that the molten metal drips onto the weld pool.
4. When welding with filler metal, move the torch in a semicircular or circular motion.
5. Allow a space between workpieces to compensate for expansion forces.
6. If possible, use carbon backing bars when welding cast iron.
7. Clean all welding surfaces at least 1″ around the seam that is to be welded.
8. Preheat cast iron to a dull red before welding.
9. Postheat cast iron after the weld is completed and then allow it to cool slowly.
10. Always use the recommended flux and filler metal when welding.
11. Use an 1100, 4043, or 5356 filler metal for welding aluminum.
12. When welding aluminum, keep the preheat temperature below 500°F (260°C).
13. When welding aluminum, use a slightly larger welding tip than is used for steel.
14. Use a neutral or slightly reducing flame for all aluminum welding.
15. When using a single-V bevel on steel, the groove angle should be 60°.
16. Steel thicker than 1/8″ should be beveled before welding.
17. On steel 1/2″ thick or more, do not fill the V in a single pass. Use several passes.
18. When backhand welding, do not swing the torch; instead, move the filler metal.
19. A double-V joint must be used with steel 1/2″ thick or more.

Exercises

Carrying a Weld Pool without Filler Metal

exercise 1

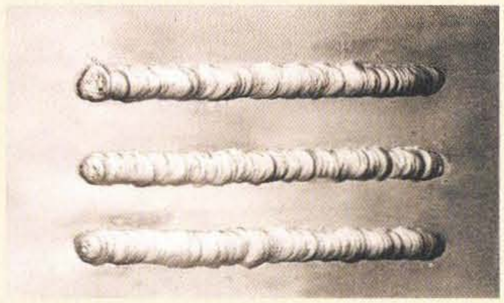
1. Obtain a piece of mild steel 1/16″ to 1/8″ thick, approximately 3″ wide, and 5″ long.
2. Be sure the surface is free of oil, dirt, and scale.
3. Light the torch and adjust it for a neutral flame.
4. Hold the inner cone of the flame approximately 1/8″ from the work and position the torch at a 45° angle to the workpiece. Move the torch from the right side of the workpiece to the left side, using a circular manipulation. Left-handed welders should reverse the direction of travel.
5. Maintain a consistent travel speed to prevent melt-through in the workpiece.
6. Practice depositing beads without filler until properly formed beads are consistently produced.



Depositing Beads with Filler Metal

exercise 2

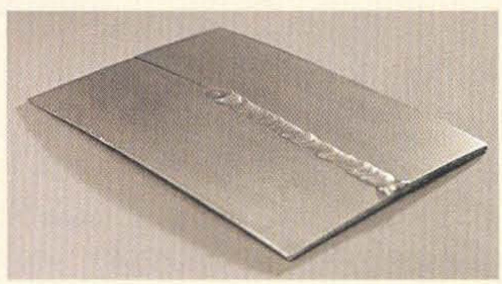
1. Obtain a piece of mild steel $\frac{1}{16}''$ to $\frac{1}{8}''$ thick, approximately 3″ wide, and 5″ long.
2. Be sure the surface is free of oil, dirt, and scale.
3. Light the torch and adjust it for a neutral flame.
4. Practice running consistent straight beads while manipulating the torch and the filler metal at the correct angles.
5. As the torch is withdrawn at the end of the pass, fill the crater by adding filler metal.



Welding a Butt Joint in Flat Position

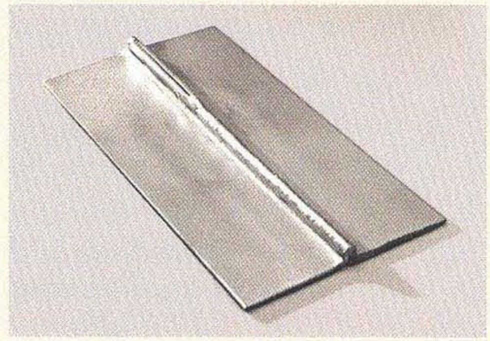
exercise 3

1. Obtain two pieces of metal $\frac{1}{16}''$ to $\frac{1}{8}''$ thick, approximately $1\frac{1}{2}''$ wide, and 5″ long.
2. Place the workpieces on two firebricks. Space for progressive spacing or tack weld the workpieces together.
3. Begin welding at the right end (or the left end if left-handed), using the same torch and filler motion as when depositing beads with filler.
4. Work the torch slowly to give the heat a chance to penetrate the joint. Add sufficient filler metal to build up the weld about $\frac{1}{16}''$ above the surface. Be sure the weld pool is large enough and the metal is flowing freely before dipping the filler metal.
5. Maintain a molten weld pool approximately $\frac{1}{4}''$ to $\frac{3}{8}''$ wide.
6. Advance the weld pool about $\frac{1}{16}''$ with each complete motion of the torch while maintaining a uniform bead width.
7. Uniform torch motion will produce smooth, even ripples.



Welding a Flange Butt Joint in Flat Position

exercise 4

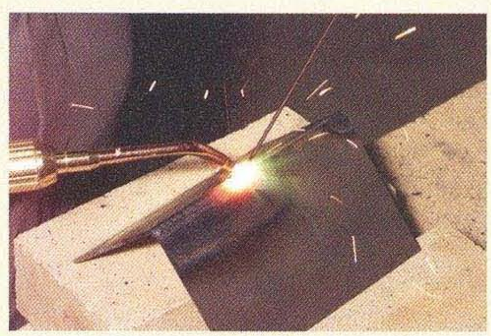


1. Obtain two pieces of metal with flanged edges.
2. Place the pieces so the flanged edges are touching. Tack weld the edges.
3. Hold the torch on one end until a weld pool is formed.
4. Carefully manipulate the torch to maintain the pool as the pool is carried along the entire joint.
5. Withdraw the torch at the end of the joint to prevent burning a hole in the joint.

Welding a Corner Joint in Flat Position

exercise 5

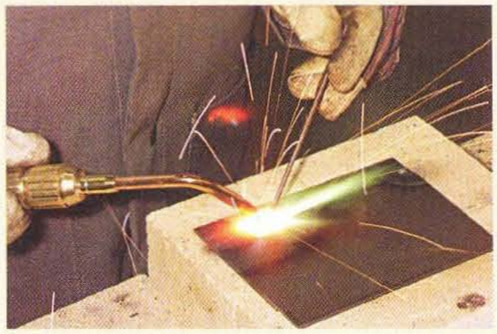
1. Obtain two pieces of metal and tack weld to form a corner joint.
2. Hold the torch on the end of the joint until a weld pool is formed.
3. Manipulate the torch to maintain the weld pool along the entire joint using a technique similar to that used on the flange joint.
4. Withdraw the torch at the end of the joint to prevent burning a hole in the joint.
5. If additional buildup is required, filler metal may be added as the weld pool is carried along the joint.



Welding a Lap Joint in Flat Position

exercise 6

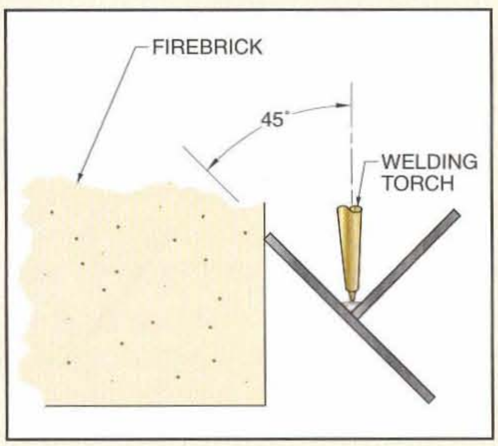
1. Obtain two pieces of metal 1/16″ to 1/8″ thick, approximately 1½″ wide, and 4″ to 5″ long.
2. Lay one workpiece on top of the other, slightly offset, and tack in place to form a lap joint.
3. Weld the workpieces using a semicircular motion of the torch.
4. While manipulating the torch and filler metal, direct more of the heat to the bottom workpiece. This may be accomplished by increasing the duration of the torch motion on the bottom workpiece. The top workpiece requires less heat and may overheat if too much heat is applied.
5. Weld one side of the workpiece and then practice on the reverse side.



Welding a T-Joint in Flat Position

exercise 7

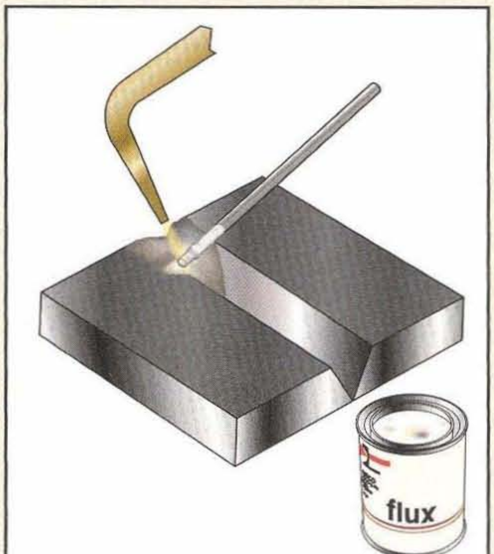
1. Obtain two pieces of metal approximately 1/16″ to 1/8″ thick, 1½″ wide, and 4″ to 5″ long.
2. Lay one workpiece flat and stand the other on top to form a T-joint. Tack weld the workpieces.
3. Tilt the tacked workpieces 45° to the work surface and place a firebrick under one side for support.
4. Hold the torch so the welding tip forms an approximately 45° angle to the bottom workpiece.
5. Using the same technique used when welding a butt joint, keep the inner cone of the flame about 1/8″ away from the deepest part of the weld.
6. Manipulate the torch constantly while adding filler metal to produce a consistent weld free from undercuts.



Welding Gray Cast Iron

exercise **8**

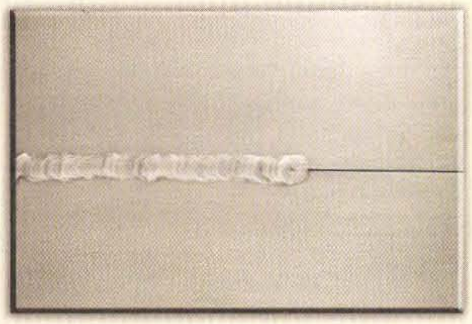
1. Obtain two pieces of cast iron and prepare the edges to be welded. Bevel the joint if necessary and remove all foreign matter from the surface.
2. Slowly heat the entire workpiece to a dull red.
3. Concentrate the flame near the starting point of the weld until the metal begins to melt. Keep the torch in the same position as in welding mild steel, with the inner cone of the flame about 1/8″ to 1/4″ from the seam.
4. When the bottom of the V is thoroughly fused, move the flame from side to side, melting down the sides so the molten metal runs down and combines with the fluid metal in the bottom of the V. Rotate the torch in a circular motion to keep the sides and bottom of the V in a molten condition. If the metal gets too hot and tends to run, raise the torch slightly.
5. Once the weld pool is molten, bring the filler metal into the outer envelope of the flame and keep it there until it is fairly hot. When the filler metal is hot, dip it into the flux. Insert the fluxed end of the filler metal into the molten pool. The heat of the weld pool will melt the filler. The filler metal should remain in the weld pool. Do not dip it into and out of the pool. As the filler metal melts, the molten metal will rise in the groove. When the metal has been built up slightly above the top surface of the workpiece, move the weld pool forward about 1″ and repeat the operation. Be sure not to move the weld pool before the sides of the V have been broken down, as this will force the molten weld pool ahead onto the cold metal.
6. When gas bubbles or white spots appear in the weld pool or at the edges of the seam, add more flux and play the flame around the specks until the impurities float to the top. Skim these impurities off the weld pool with the filler metal. Tapping the filler metal against the bench will remove impurities.
7. After the weld is completed, postheat the entire workpiece to a dull red. Allow the casting to cool slowly by covering with a blanket.
8. To test the weld sample, place it in a vise. The weld should be flush with the top of the jaws. Wearing proper eye protection, strike the upper end of the workpiece with a heavy hammer until the workpiece breaks. If the metal has been welded properly, the break should occur in the base metal, not along the welded line.



Welding Aluminum

exercise 9

1. Obtain two pieces of aluminum and prepare the workpieces to be welded.
2. Preheat the workpiece to the proper temperature.
3. Flux the workpieces using the recommended flux.
4. Pass the flame over the starting point until the flux melts.
5. Scrape the surface with the filler metal at about 3- or 4-second intervals, permitting the filler metal to come clear of the flame each time; otherwise, it will melt before the base metal. The scraping action indicates when welding should begin without overheating the aluminum.
6. Using the forehand welding technique, angle the torch at a low angle (less than 30° above horizontal when welding thin material). The torch should be moved forward without any side-to-side motion.
7. While moving forward, periodically dip the filler metal into, and withdraw it from, the weld pool. This method of withdrawal closes the weld pool, prevents porosity, and assists the flux in removing the oxide film.
8. Maintain the same procedure throughout welding.
9. A correct oxyacetylene weld on aluminum will have the necessary penetration with the correct bead ripple and contour.



Welding a Backhand Weld

exercise 10

1. Obtain two pieces of ¼″ mild steel and bevel the edges.
2. Form a butt joint with the beveled edges about 1/16″ apart and tack together.
3. Position the workpiece so the weld joint is in horizontal position.
4. Start the weld at the left edge of the workpiece if right-handed (the right edge if left-handed) and bring the edges of the V to a molten state. Hold the end of the filler metal in the outer envelope of the flame so it melts as soon as the weld pool forms.
5. At the start, concentrate the flame slightly more on the bottom of the V. Once the weld pool is fluid, dip the filler metal into it. As the weld pool moves, direct the flame more on the filler metal and build up the weld pool to the top of the V. As the molten metal fills up the V, move the filler metal slightly from side to side to ensure that the weld metal fuses evenly with the edges of the base metal.
6. To test the weld, cut off several 1″ strips. Grind off the surplus weld metal so that the top of the weld (face) is flush with the top of the workpiece (specimen). The grind marks should run lengthwise on the specimen to prevent premature failure during testing. Place the specimen in the guided bend tester. Apply pressure to the specimen. If the weld is satisfactory, there should be no indications of cracking or fracturing. Use proper eye protection when testing each specimen.

Welding a Single-V Butt Joint in Flat Position

exercise 11

1. Obtain two pieces of ¼″ mild steel and bevel the edges.
2. Form a butt joint with the beveled edges about ¹⁄₁₆″ apart and tack together.
3. Position the workpiece so the weld joint is in flat position.
4. Use ³⁄₁₆″ filler metal. Use the correct size tip for the weld.
5. Hold the torch at an angle 60° from the vertical, rather than the 45° angle used for other steels.
6. Direct the flame onto the V and, as the edges begin to melt, dip the tip of the filler metal into the weld pool. Before adding filler metal, ensure that the sides of the V are thoroughly molten to the bottom of the V. Fill in the bottom of the V about ½″, with the weld pool extending upward to one-half the depth of the V. While the weld pool is still molten, swing the torch in a semicircular motion and fill the V. The completed bead should be between ⅜″ and ½″ wide and project slightly above the surface of the workpiece. Return the flame to the bottom of the V, advance another ½″, and again raise the bead section to the top of the V. Continue until the weld is finished.
7. To test the weld, cut off several 1″ strips. Grind off the surplus weld metal so that the top of the weld (face) is flush with the top of the workpiece (specimen). The grind marks should run lengthwise on the specimen to prevent premature failure during testing. Place the specimen in the guided bend tester. Apply pressure to the specimen. If the weld is satisfactory, there should be no indications of cracking or fracturing. Use proper eye protection when testing each specimen.

QUESTIONS FOR STUDY AND DISCUSSION

1. Why is a filler metal used in welding?
2. What determines the size of the filler metal that should be used?
3. Where is the filler metal inserted when depositing beads with filler metal?
4. What happens if the filler metal is too large for the base metal that is being welded? If it is too small?
5. How should the torch be manipulated when using filler metal on a butt weld?
6. If the metal does not melt readily, what is the probable cause?
7. What happens if the torch is moved forward too slowly?
8. Why should cast iron pieces be preheated before welding?
9. Why is flux necessary when welding cast iron?
10. What is the melting point of aluminum?
11. What type of filler metal is recommended for welding aluminum?
12. How can it be determined when aluminum has reached its preheating temperature?
13. How are smooth, even ripples formed in the weld bead?
14. How is the flux manipulated in order to deposit it in the weld?
15. If cast iron has been properly welded, where should the break occur when the completed weld is tested?
16. Why should the edges be beveled when heavy steel is ⅛″ thick or more?
17. At what angle should the torch be held when welding heavy steel?
18. How should the torch and filler metal be handled in backhand welding? At what angle?
19. When welding heavy steel over ½″ thick, why use more than one pass?

7 OAW–Other Positions

Oxyacetylene welding cannot always be done in flat position. Occasionally, workpieces must be welded in the horizontal, vertical, or overhead positions. Welding in flat position is easier and somewhat faster than other positions; however, with practice, welding in other positions can be performed easily.

When welding in horizontal, vertical, or overhead position, the main obstacle to obtaining a sound weld is the gravitational pull downward on the molten metal.

HORIZONTAL AND VERTICAL WELDING

When welding in horizontal or vertical position, a jig or positioner may be used to hold the workpieces in position. A semicircular torch movement should be used for horizontal and vertical welding. Maintaining a consistent size weld pool helps control the weld and prevent sagging.

As welding progresses in horizontal welding, metal has a tendency to build up much more on the edge of the bottom workpiece. To overcome this tendency, direct the flame longer on the edge of the bottom workpiece without allowing the weld pool to drop. Hold the torch so the tip forms an angle of 45° to the workpiece and to the line of the weld. Point the filler metal toward the welding tip at an angle of approximately 30° to the line of the weld and 15° to 20° to the horizontal workpiece. Direct the flame evenly over both workpieces. To prevent undercutting, add filler metal nearer the top workpiece.

Vertical welding is performed uphill or downhill. *Uphill welding* is welding performed with an uphill progression. See Figure 7-1. *Downhill welding* is welding performed with a downhill progression. When vertical welding, do not allow the weld pool to become too large. If the weld pool gets too big or too fluid, it could get out of control and run down the face of the weld. If the weld gets too fluid, pull the flame away slightly so that it does not play directly on the weld pool.

Use a semicircular torch movement for horizontal, vertical, and overhead welding.

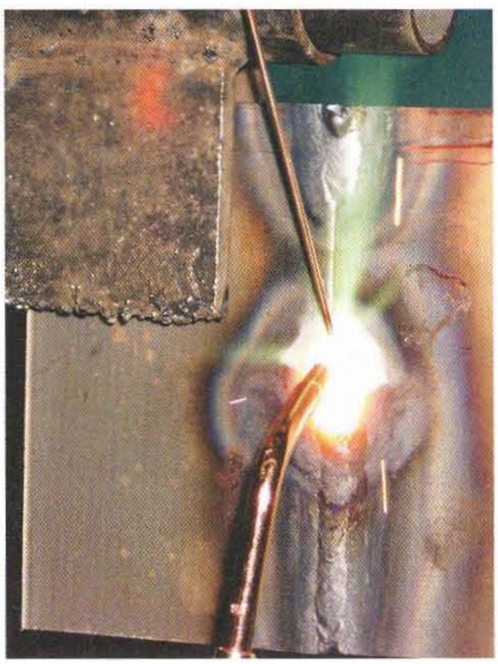


Figure 7-1. *Uphill welding is performed with an uphill progression. Do not allow the weld pool to get too large.*

In horizontal welding, direct the flame more on the edge of the lower workpiece.

OVERHEAD WELDING

Overhead welding is more difficult to perform than horizontal or vertical welding because of the unusual working position and the skill needed to keep the molten weld pool from dropping off the workpieces.

Overhead welding is possible beause molten metal has cohesive (sticky) qualities, as long as the weld pool does not get too large. Molten metal does not fall from the weld if the weld pool is not allowed to form in complete drops.

The amount of heat directed on the joint must be carefully regulated, since excessive heat increases the flow of the molten metal.

On overhead welds, move the filler metal slowly in a circular or swinging motion.

Use the same semicircular motion of the torch for overhead welding as for other welding positions. Move the filler metal slowly in a circular or swinging motion to help keep the weld pool shallow. The movement of the filler metal distributes the molten weld pool and prevents it from forming large drops and falling off. See Figure 7-2. If the weld pool becomes too fluid and starts to run, move the torch slightly away from the joint.

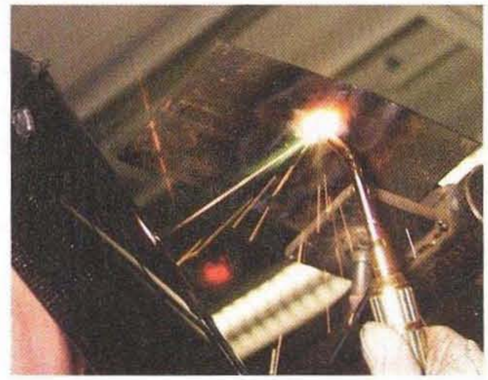


Figure 7-2. *The filler metal moves ahead of the torch and distributes the molten weld pool as it is moved.*

POINTS TO REMEMBER

1. Use a semicircular torch movement for horizontal, vertical, and overhead welding.
2. To maintain control and prevent sagging, do not allow the weld pool to become too large.
3. If the weld pool becomes too fluid, raise the flame slightly away from the workpieces.
4. In horizontal welding, direct the flame more on the edge of the lower workpiece.
5. On overhead welds, move the filler metal slowly in a circular or swinging motion.

Exercises

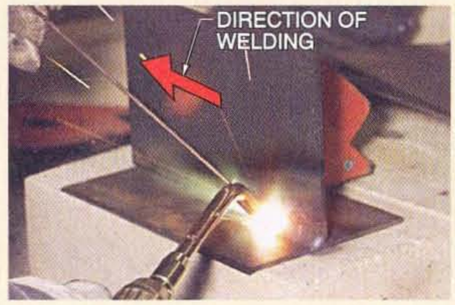
Welding a Butt Joint in Horizontal Position

exercise 1

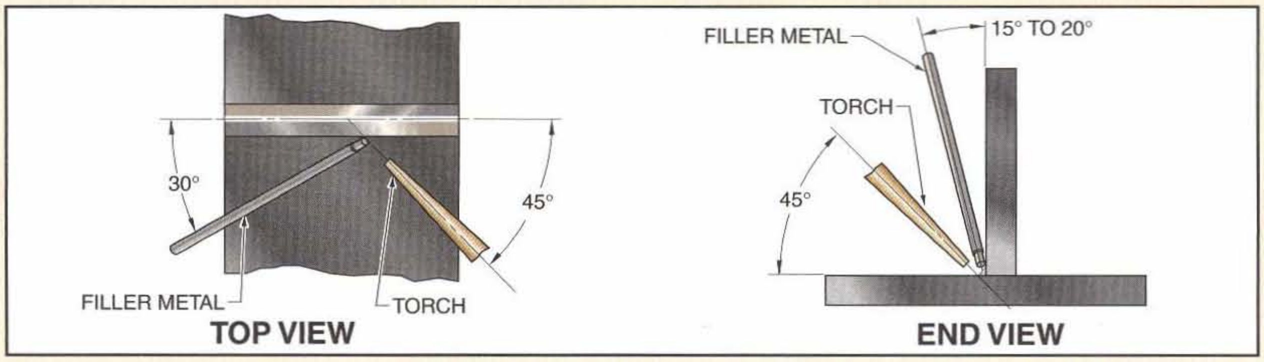
1. Obtain two pieces of 1/16″ or 1/8″ mild steel.
2. Form a butt joint, with a root opening for expansion, and tack together.
3. Position workpiece so the weld joint is in horizontal position.
4. Start welding at the right edge if right-handed (or the left, if left-handed), using a semicircular torch motion. As welding progresses, gravity can cause metal to build up on the bottom workpiece. To overcome this tendency, direct the flame longer on the edge of the bottom workpiece and keep the tip of the filler metal nearer to the top workpiece.

Welding a T-Joint in Horizontal Position

exercise 2

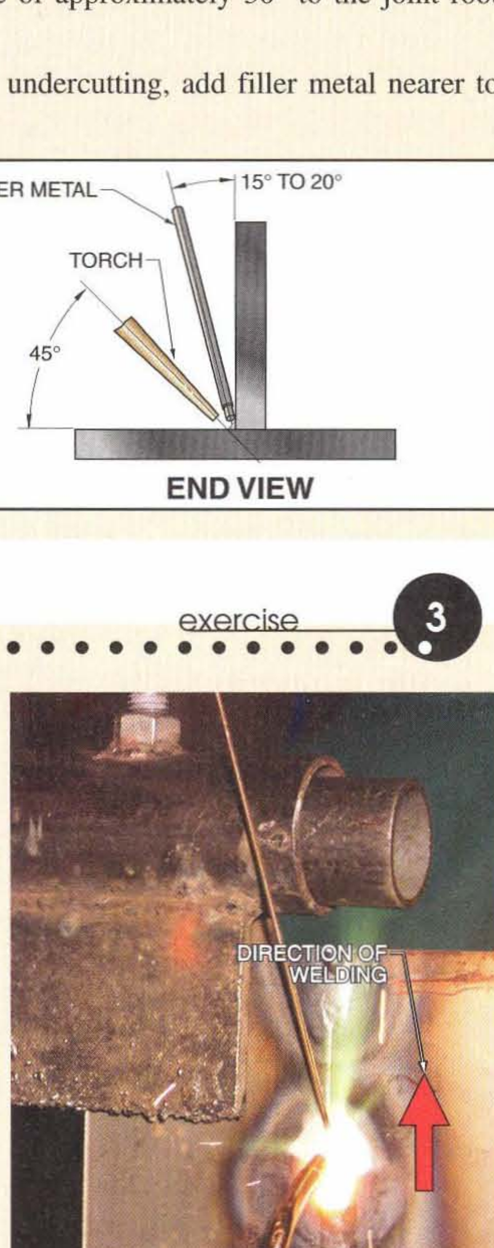


1. Obtain two pieces of 1/16″ or 1/8″ mild steel.
2. Form a T-joint with the pieces at a 90° angle and tack together.
3. Position the workpiece so the weld joint is in horizontal position.
4. Start welding at the right edge if right-handed (or the left, if left-handed), using a semicircular torch movement.
5. Hold the torch so the tip forms a 45° angle to the bottom workpiece, and a 45° angle pointing to the end of the weld.
6. Point the filler metal toward the welding tip at an angle of approximately 30° to the joint root and 15° to 20° to the bottom workpiece.
7. Direct the flame evenly over the workpiece. To prevent undercutting, add filler metal nearer to the vertical workpiece.



Welding a Butt Joint in Vertical Position

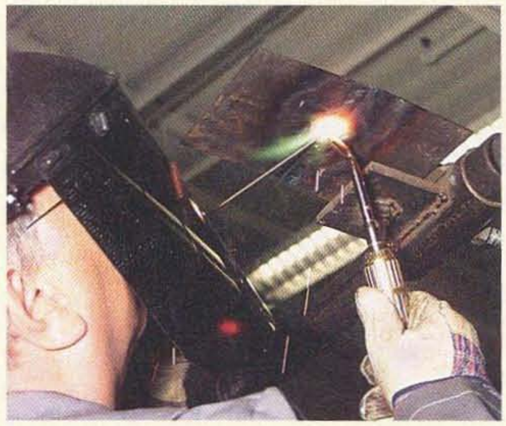
exercise 3



1. Obtain two pieces of 1/16″ or 1/8″ mild steel.
2. Form a butt joint, with a root opening for expansion, and tack together.
3. Position the workpiece so the weld joint is in vertical position.
4. Hold the torch and filler metal at the same angle as in flat position. As welding progresses, vary the torch angle as necessary to control the weld pool.
5. Weld uphill. Start the weld at the bottom edge and work upward, using a semicircular torch motion. Do not allow the weld pool to become too large or it will run down the face of the weld.
6. To prevent the weld pool from becoming too fluid, direct more of the flame on the filler metal. If the weld pool becomes too fluid, pull the flame away slightly.

Welding a Butt Joint in Overhead Position

exercise 4



1. Obtain two pieces of 1/16″ or 1/8″ mild steel.
2. Form a butt joint, with a root opening for expansion, and tack together.
3. Position the workpiece so the weld joint is in overhead position. The weld joint should allow clearance for manipulating the torch.
4. Use the same semicircular motion of the torch as other welding positions. Move the filler metal slowly in a circular or swinging motion to help keep the weld pool shallow. The movement of the filler metal also distributes the molten weld pool to prevent it from forming large drops and falling off.
5. If the weld pool has a tendency to run, pull the torch slightly away from the surface.

? QUESTIONS FOR STUDY AND DISCUSSION

1. What can be done to prevent the weld pool from sagging when welding in vertical position?
2. At what angle should the torch be held for horizontal welding?
3. How should the torch be moved for vertical, horizontal, and overhead welding?
4. In horizontal welding of a butt joint, why should the flame be directed more on the edge of the lower workpiece?
5. What should be done when welding in vertical position to prevent the weld pool from becoming too fluid?
6. Why is overhead welding more difficult to perform than horizontal or vertical welding?
7. How can the weld pool be prevented from dropping off in overhead welding?
8. How should the filler metal be manipulated in overhead welding?
9. What can be done to prevent undercutting of the weld when welding a horizontal T-joint?
10. What can be done to maintain a shallow weld pool when welding in the overhead position?

8 SMAW–Equipment

Shielded metal arc welding (SMAW), sometimes referred to as stick welding, is used in the fabrication of many products, including ships, pressure vessels, tanks, automobiles, and appliances. SMAW welding machines are used to weld light- and heavy-gauge metals of all kinds.

A constant-current welding machine is used for SMAW. Power to produce a welding arc can be static, such as is supplied by a transformer, transformer-rectifier, or inverter; or engine-driven. The power source design is selected based on the requirements of the welding task.

Proper personal protective equipment must be used during welding to protect the welder from injury and to prevent damage to the materials or structures being welded.

ELECTRICAL PRINCIPLES

When welding using SMAW, an electrical circuit is created. An *electrical circuit* is a path taken by electric current flowing from one terminal of the welding machine, through a conductor, and to the other terminal. *Current* is the amount of electron flow through an electrical circuit.

A *conductor* is any material through which electricity flows easily. Conductors can be found in the form of wire, cable, or busbars. A person can also act as a conductor of electricity. When welding using the SMAW process, the welding leads serve as conductors in the circuit. *Resistance* is the opposition of the material in a conductor to the passage of electric current, causing the electrical energy to be transformed into heat. Resistance is measured in ohms. An *ohm* is the basic unit of measurement of resistance. One ohm is the result of 1 volt applied across a resistance that allows 1 ampere to flow through it.

Welding Current

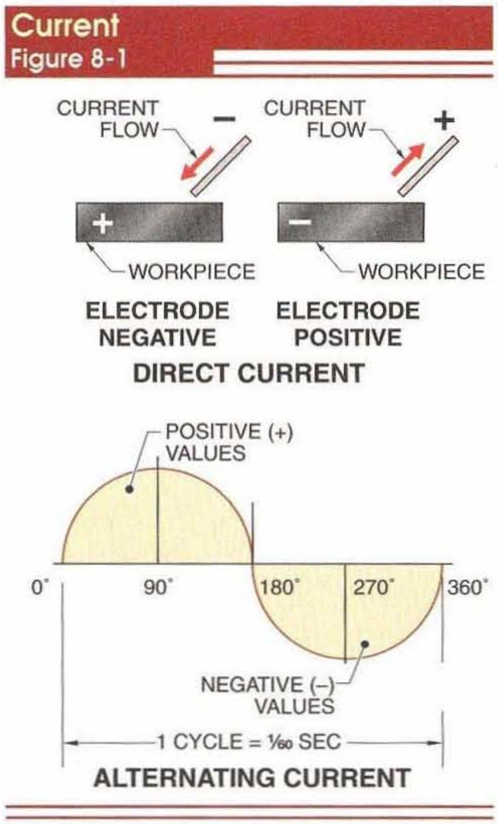
When electrical current moves through a wire, heat is generated by the resistance of the wire to the flow of electricity. The greater the current flow, the greater the heat generated. The heat generated during the SMAW process comes from an arc that develops when electricity jumps across an air/gas gap between the end of an electrode and the base metal. The air/gas gap produces a high resistance to the flow of current. This resistance generates intense heat that can range from 6000°F (3300°C) to 10,000°F (5500°C).

The heat used for SMAW is generated from an arc that develops when electricity jumps across an air/gas gap between the end of the electrode and the base metal. The air/gas gap produces high resistance to current flow, generating intense heat.

Welding current can be direct current (DC) or alternating current (AC). Current has the most effect on the depth of penetration into the base metal.

Direct current (DC) is an electrical current that flows in one direction only. This means that there is no change in the direction of current flow. *Alternating current (AC)* is an electrical current that has alternating positive and negative values. In the first (positive) half-cycle, the current flows in one direction; the current then reverses and for the second (negative) half-cycle flows in the opposite direction. See Figure 8-1.

Figure 8-1. *Direct current flows in one direction only. Alternating current has positive values and negative values; current flows in one direction, then reverses and for the second half-cycle flows in the opposite direction.*



The rate of change is referred to as frequency. *Frequency* is the number of cycles per second in an AC sine wave. Frequency is indicated as 25, 40, 50, or 60 cycles per second. Frequency is measured in hertz (Hz). *Hertz (Hz)* is the international unit of frequency equal to 1 cycle per second. In the United States, alternating current is 60 cycles per second (60 Hz).

An *ampere (amp,* or *A)* is a unit of measure for electricity that expresses the quantity, or number, of electrons flowing through a conductor per unit of time. *Amperage* is the quantity of electricity measured. An *ammeter* is an instrument that measures amperage (amperes).

The primary voltage (input) to a welding machine may be 120 V, 230 V, 460 V, or 600 V. The welding machine frame (chassis) must be well grounded since primary voltages can be very dangerous.

Polarity. *Polarity* is the positive (+) or negative (–) state of an object. Polarity determines the direction of current flow in a DC circuit. Since current moves in one direction only in a DC circuit, polarity must be selected for some welding operations. DC current used for welding can be either direct current electrode negative (DCEN) or direct current electrode positive (DCEP). See Figure 8-2. The terminology DCEN and DCEP replaces the formerly used terms straight polarity (DCEN) and reverse polarity (DCEP).

Polarity is changed by connecting the electrode lead to either the positive or negative terminal. When the electrode lead is connected to the negative terminal of the welding machine and the workpiece lead is connected to the positive terminal, the polarity is DCEN. When the electrode lead is connected to the positive terminal of the welding machine and the workpiece lead is connected to the negative terminal, the circuit is DCEP. On some machines, polarity is changed by moving a switch or lever on the welding machine to DCEN (–) or DCEP (+). Polarity is of no consequence in AC welding machines because current is constantly changing direction.

The voltage and current output of a welding machine should be regularly tested to ensure that the proper levels are available for welding.

Polarity
Figure 8-2

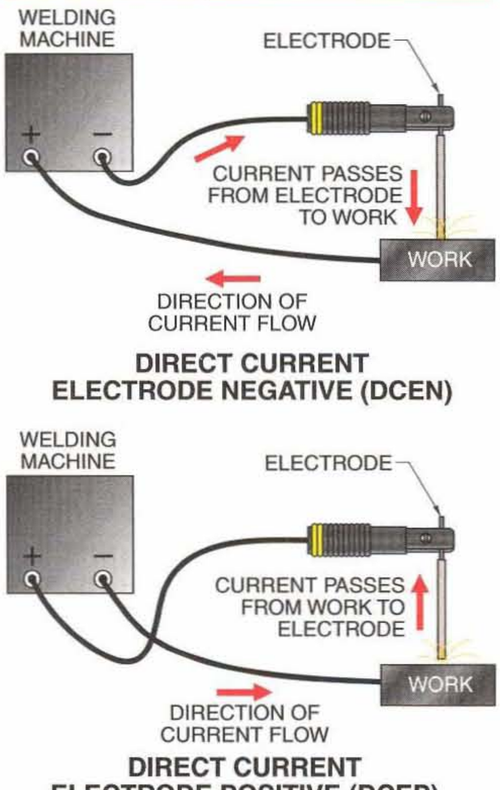
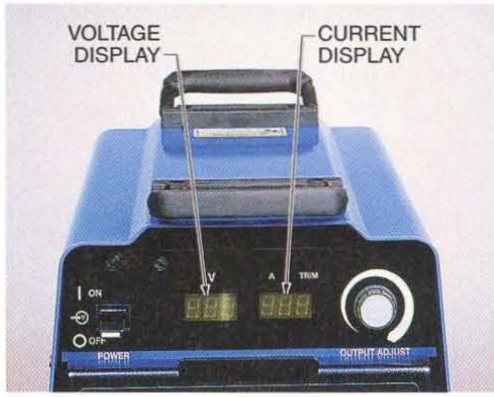


Figure 8-2. *When welding with DC current, polarity can be changed from DCEN to DCEP to control the amount of heat directed to the base metal.*



Miller Electric Manfacturing Company

Figure 8-3. *Voltage and current values can be shown on a digital display on the front of a welding machine.*

Polarity determines the location of heat concentration in a welding circuit. With DCEN, more heat is located in the workpiece. With DCEP, more heat is directed to the electrode. The type of welding to be performed and the electrode used determine the polarity. Electrodes are designed for use with a specific polarity.

Voltage

The force (electromotive force, or emf) or pressure that causes current to flow in a circuit is called voltage. *Voltage* is the amount of electrical pressure in a circuit. Voltage does not flow, only current flows. Voltage is measured using a voltmeter. Voltage and current values are commonly shown with a digital display on the front of a welding machine. See Figure 8-3.

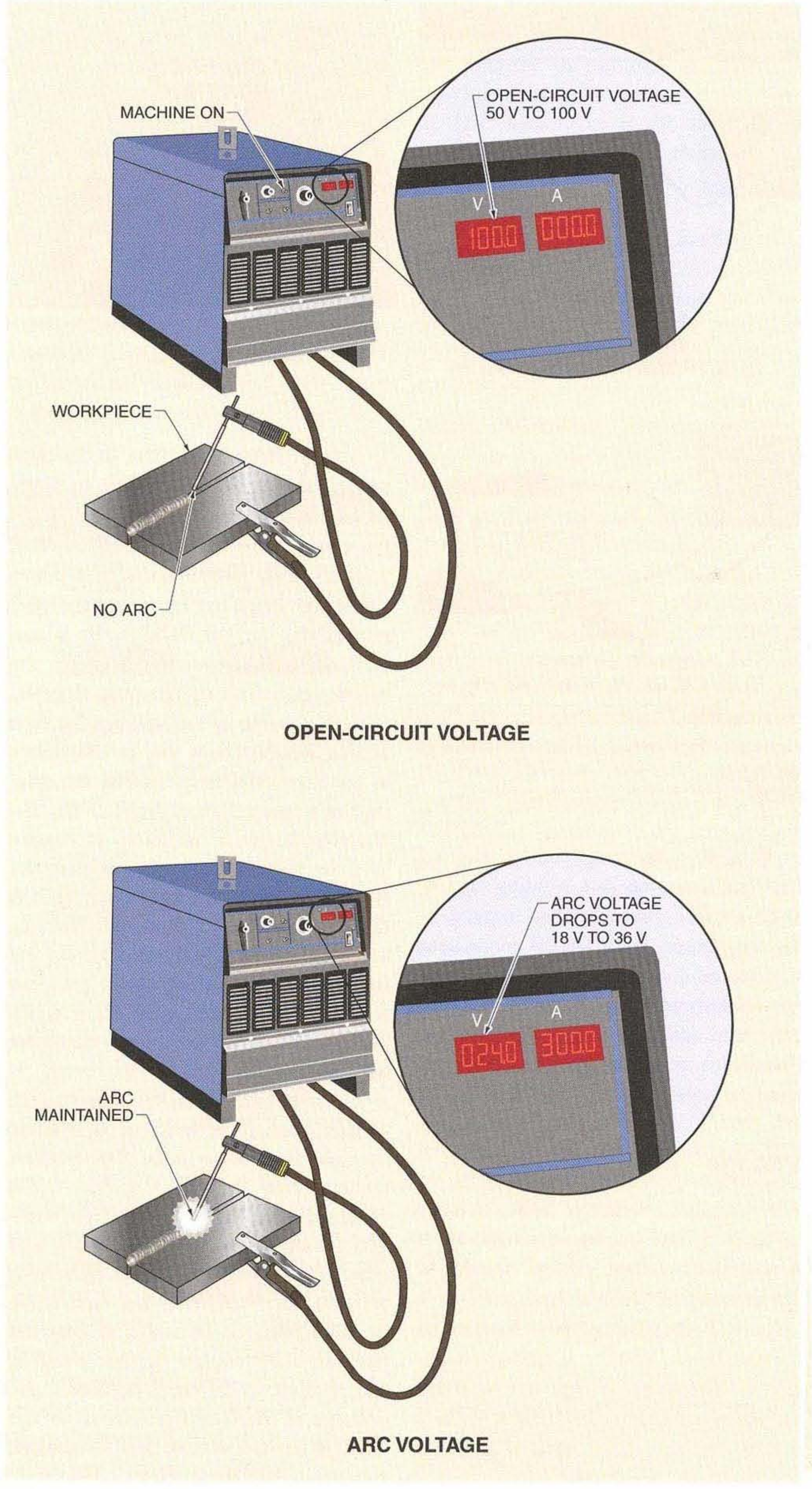
Voltage (force) is similar to the pressure used to make water flow in pipes. In a water system, a pump provides the pressure to make the water flow, whereas in an electrical circuit a power supply produces the force (voltage) that pushes the current through the wires. Voltage has the most effect on the height and width of the weld deposit.

Voltage drop is the voltage decrease across a component due to resistance to the flow of current. Just as the pressure in a water system drops as the distance from the water pump increases, so does voltage lessen as the distance from the generator increases. When there is too great a drop, the welding machine cannot supply enough current for welding. A voltage drop problem is usually associated with using welding cables that are too long or that have been damaged.

Open-circuit voltage is the voltage produced when the machine is ON and no welding is being done. Open-circuit voltage varies from 50 V to 100 V. *Arc voltage (working voltage)* is the voltage present after an arc is struck and maintained. Arc voltage is generally between 18 V and 36 V. See Figure 8-4. An adjustment is provided to vary the open-circuit voltage so that welding can be done in different positions. Arc voltage is measured as close to the welding arc as possible and to measure voltage loss in the circuit.

Polarity affects the amount of heat directed to the workpiece. By changing polarity, heat can be concentrated where it is most needed.

Figure 8-4. *Open-circuit voltage (usually between 50 V and 100 V) is voltage produced when the welding machine is ON; arc voltage is the working voltage (usually between 18 V and 36 V) after an arc is struck.*



The actual voltage used to provide welding current is low (18 V to 36 V), whereas high current is necessary to produce the heat required for welding. The low voltage and high current used for welding are not particularly dangerous if proper grounding and insulation are used.

Circuits

The electrical circuit used for welding starts at the negative terminal of the welding machine where current is produced, moves through the wire or cable to the electrode, through the work, and then returns to the positive terminal of the welding machine. See Figure 8-5. Welding machines used for SMAW provide the current and voltage required for the specific welding task.

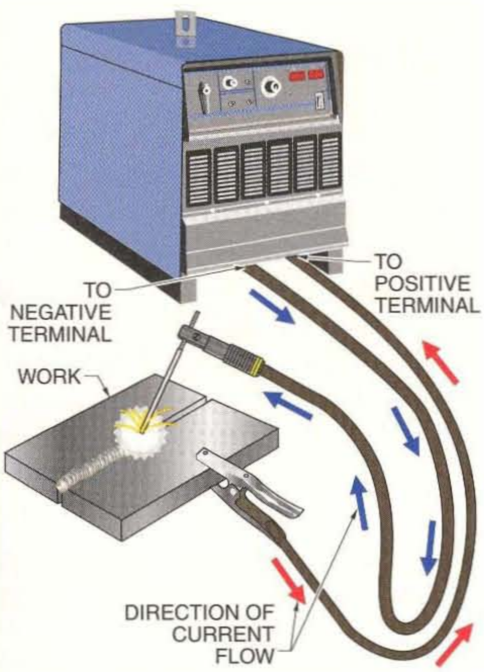


Figure 8-5. *DCEN current, in which electric current flows from the negative terminal of the welding machine, moves along the wire or cable to the electrode, through the work and then returns to the positive terminal, is commonly used for SMAW.*

All welding equipment must be maintained and serviced. The welder is responsible for checking the fluid levels (water, oil, fuel) on all fuel-operated machines. Electrode leads and holders should be checked regularly to ensure a tight connection and for proper grounding. Loose connections generate heat and burn leads and connections.

WELDING MACHINE OUTPUT

Welding machine output can be alternating current (AC), direct current (DC), or alternating current/direct current (AC/DC), depending on the welding task. See Figure 8-6. The electrode used must match the current produced by the welding machine.

Welding Machine Output
Figure 8-6

Figure 8-6. *Welding current is provided by AC, DC, or AC/DC output.*

Alternating Current (AC)

AC current output provides a constantly alternating current that can be used for SMAW welding. AC current allows a welder to easily maintain an arc during welding. Other features of AC current include low operating and maintenance costs, and high overall electrical efficiency. AC welding machines typically operate on single-phase (1ϕ) primary power.

Direct Current (DC)

DC current output for SMAW may use single-phase (1ϕ) or three-phase (3ϕ) primary electrical power. The most stable DC welding is provided by welding machines that provide 3ϕ transformers and full-wave rectifiers. DC output usually has polarity switches with both positive and negative terminals.

Alternating Current/Direct Current (AC/DC)

AC/DC current output is available on constant-current welding machines that operate using a 1ϕ or 3ϕ primary power source. The main difference between AC and AC/DC output for SMAW is that AC/DC contains a rectifier. Rectified 1ϕ welding power is not as stable as rectified 3ϕ DC welding power. AC/DC welding machines are commonly used for SMAW. See Figure 8-7.

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Figure 8-7. *An AC/DC output welding machine is commonly used for SMAW.*

CONSTANT-CURRENT WELDING MACHINES

Constant-current welding machines are designed primarily for SMAW. A *constant-current welding machine* is a welding machine in which a steady supply of current is produced over a wide range of welding voltages caused by changes in arc length. All welding machines used for SMAW are constant-current. Constant-current welding machines have a severe negative volt-amp curve with a limited maximum short circuit current. See Figure 8-8.

Constant Current
Figure 8-8

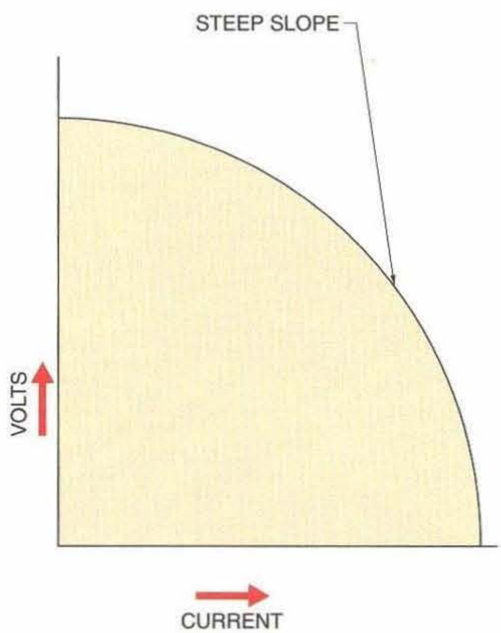

Figure 8-8. *A constant-current welding machine has a steeply sloping volt-amp curve to control the arc and welding heat.*

A *volt-amp curve* is a curve that shows how the voltage varies in its relationship to current between the open circuit (where there is static electrical potential but no current is flowing) and short circuit (where the electrode touches the workpiece).

When using a constant-current welding machine under normal welding conditions, the open-circuit voltage is between 50 V and 100 V but the output arc welding voltage is between

18 V and 36 V. By having a high open-circuit voltage, arc starting is easier. As welding progresses, the high voltage drops to the arc (working) voltage. Regardless of the arc length caused by raising or lowering the electrode, the current output does not fluctuate appreciably. The actual arc voltage varies, depending on the length of the arc.

To strike an arc, the electrode must be shorted to the workpiece. At the moment of contact (short circuit), the current increases while the voltage drops. As the electrode moves away from the workpiece, the voltage rises to maintain the arc while the current drops to the required working level. If the arc length increases, the arc voltage increases. Conversely, if the arc length decreases, the arc voltage decreases. The welder can vary the arc voltage by lengthening or shortening the arc.

During SMAW, whether using AC or DC current, it may be difficult to maintain a consistent arc length. However, with a constant-current machine, there are relatively small changes in current with any changes in arc length. The result is that the welding heat and burn-off rate of the electrode are affected very little, permitting the welder to maintain good control of the weld pool.

STATIC POWER SOURCES

Static power sources used in a welding machine have no internal moving parts. They convert power from a utility line to the power needed for welding. Utility line power is typically supplied by a local utility company. Common static power sources include transformers, transformer-rectifiers, and inverters.

Based on the welding task, the welding leads are plugged into the terminals on the front of the welding machine to supply the desired welding current output. See Figure 8-9. Depending on how the leads are plugged in, electrode positive or electrode negative current is supplied.

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Figure 8-9. *Based on the welding task, the welding leads are plugged into the terminals on the front of the welding machine to supply the desired welding current output.*

Transformers

A *transformer* is an electrical device that changes voltage from one level to another. A transformer produces AC current. A transformer takes power directly from a power supply line and transforms it to the voltage required for welding.

Some transformers also have an arc booster switch that supplies an increase in current for easy arc starting as soon as the electrode comes in contact with the work. After the arc is struck, the current automatically returns to the level set for the job.

Transformer-Rectifiers

A *rectifier* is an electrical device contained within a transformer welding machine that changes AC current into DC current. A transformer-rectifier power source is sometimes preferable because it is usually more electrically efficient than an engine-driven power source, and provides quiet operation. Current is controlled by a switching

arrangement where one switch sets the desired current range and a second switch is for fine adjustment before or during welding. Some small rectifiers are 1ϕ, but a 1ϕ rectifier does not provide as smooth an arc as a 3ϕ rectifier. See Figure 8-10.

A half-wave rectifier produces an unbalanced sine wave by allowing only the positive half of the sine wave to pass. Current does not flow during the negative half of the cycle, resulting in an erratic current output that is usually unsuitable for welding.

Figure 8-10. *A transformer-rectifier power source can be adapted for a variety of welding applications.*

Transformer-Rectifiers
Figure 8-10

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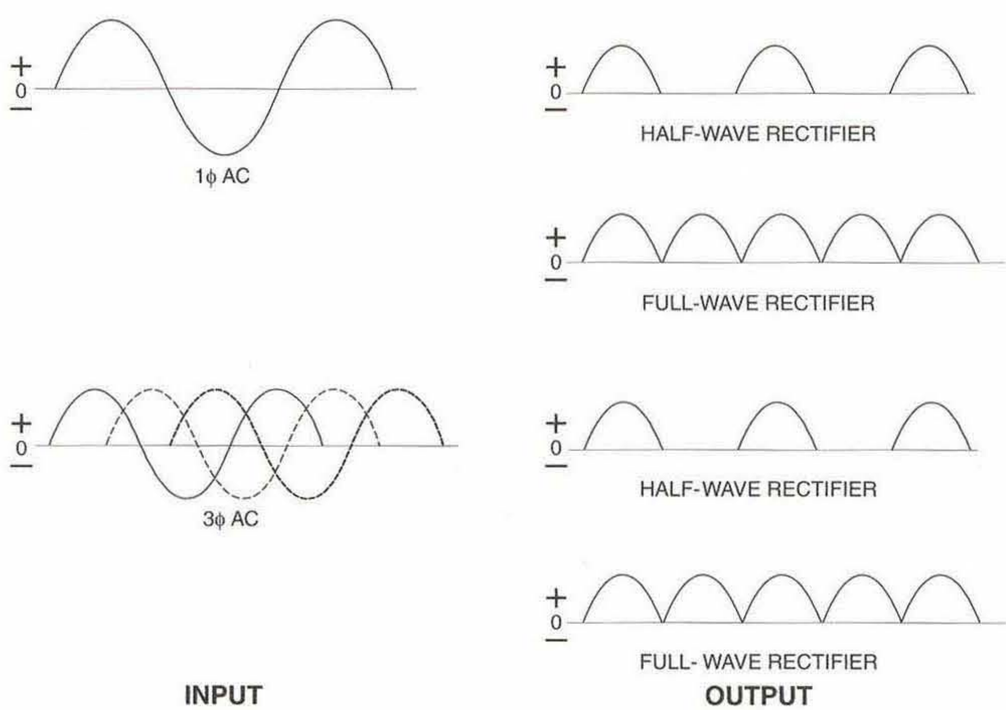

A full-wave rectifier, which uses four diodes in the circuit, produces a sine wave that is smoother than a half-wave rectifier. Additional diodes can be used to produce a smoother output, depending on the requirements of the welding job.

Inverters

An *inverter* is an electrical device that changes DC current into AC current. An inverter power source uses transistors to convert DC current into high-frequency AC current. An inverter can be designed to produce variable frequency to provide fine-tuned adjustment of the welding arc. See Figure 8-11.

Variable Frequency
Figure 8-11

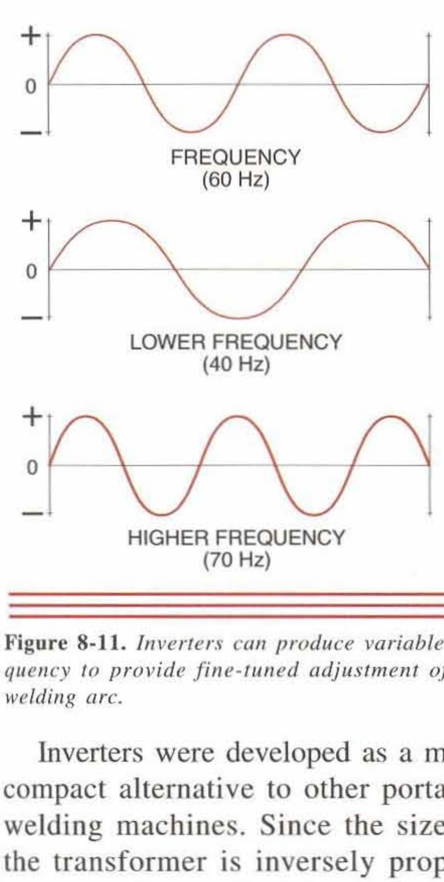

Figure 8-11. *Inverters can produce variable frequency to provide fine-tuned adjustment of the welding arc.*

Inverters were developed as a more compact alternative to other portable welding machines. Since the size of the transformer is inversely proportional to the applied frequency, an inverter can be as much as 75% smaller than conventional welding machines. Inverters require less electricity than conventional welding machines and have a faster response time. Also, the aluminum windings of conventional welding machines have been replaced by copper, making the inverter smaller and more compact, but also more expensive.

ENGINE-DRIVEN POWER SOURCES

Engine-driven power source designs use gasoline, diesel fuel, or propane to run the engine and an alternator or generator to provide the power for welding. Gasoline- and diesel-powered welding machines are typically used in the field where electricity is not available. See Figure 8-12. When using an engine-driven power source, make sure there is oil, water, and the correct fuel in the machine.

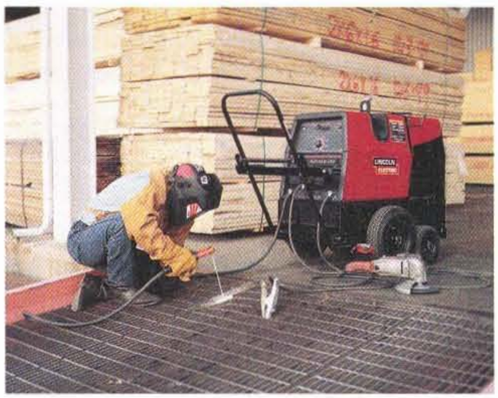

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Figure 8-12. *Engine-driven power sources make welding possible in areas where electricity is not available.*

Generators used for SMAW are usually constant-current, dual-control. With a dual control, the current is adjusted by two controls. One control provides an approximate, or coarse, current setting. The second control is usually a rheostat that provides a fine adjustment of the welding current to increase or decrease the heat. Some generators provide a choice between low voltage and high open-circuit voltage. A high open-circuit voltage with a drooping voltage characteristic is used for SMAW.

On dual-control generators, the slope of the output current can be varied to produce a soft or harsh arc. By flattening the volt-amp curve (increasing current), a digging arc can be obtained for deeper penetration. With a steeper curve (reduced current

in relation to voltage), a soft or quiet arc results, which is useful for welding light-gauge metals. A generator with dual control allows greater flexibility for welding metals of different thicknesses.

WELDING MACHINE RATINGS

Welding machines are rated (sized) according to their current at a voltage output at 60% duty cycle, such as 150 A, 200 A, 250 A, 300 A, 400 A, 500 A, or 600 A. The rating is the current output at the working terminal. Thus, a machine rated at 150 A can be adjusted to produce a range of power up to 150 A. The welding machine rating required is determined by the type of welding performed. A general guide to welding machine rating (size) and service is as follows:

- 150 A to 200 A. Light- to medium-duty welding. Excellent for all fabrication purposes, and rugged enough for continuous operation on light or medium production work.
- 250 A to 300 A. Average welding requirements. Used in plants for production, maintenance, toolroom work, and general shop welding.
- 400 A to 600 A. Large-capacity, heavy-duty welding. Used extensively in heavy structural work, fabricating heavy machine parts, heavy pipe and tank welding, cutting scrap and cast iron, and for a wide range of welding applications.

The National Electrical Manufacturers Association (NEMA) has set a standard for duty cycle based on a 10 min period. The duty cycle standard expresses the actual operation time that a welding machine may be used at its rated load without exceeding the temperature limits of the insulation of the component parts.

Duty Cycle

Duty cycle is the percentage of time during a specified period that a welding machine can be operated at its rated load without overheating. The National Electrical Manufacturers Association (NEMA) has set a standard based on a 10 min period. The 10 min period expresses the actual operation time that a welding machine may be used at its rated load without exceeding the temperature limits of the insulation of the component parts. See Figure 8-13.

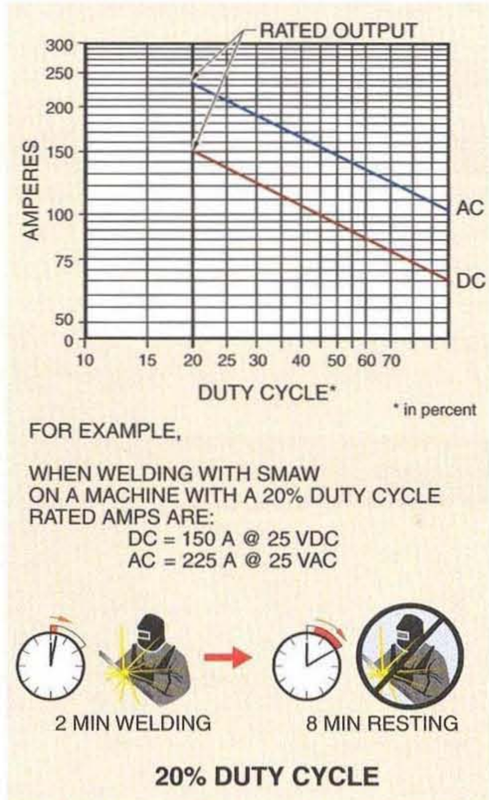


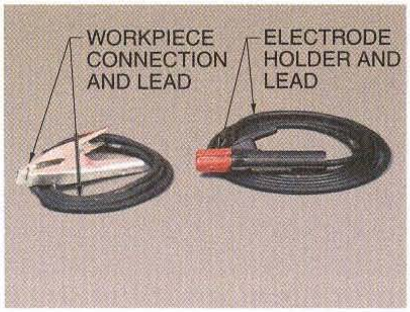
Figure 8-13. *Duty cycle is the time during a specified test period that a welding machine can be operated at its rated load without overheating.*

A welding machine rated at 300 A at 32 V, 60% duty cycle can put out the rated current at the rated voltage for 6 min out of every 10 min. The machine must idle and cool the other 4 min of every 10 min. Some welding machines used for automatic welding are rated at 100% duty cycle and can be run continuously without overheating.

WELDING EQUIPMENT

Welding equipment used for SMAW must be kept in good repair. Tools should be regularly inspected for signs of wear or damage. Required welding equipment includes welding cables, electrode holders, and work clamps/leads. See Figure 8-14.

Welding Equipment
Figure 8-14



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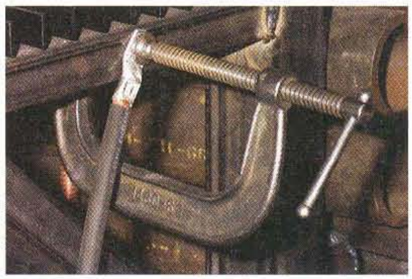
WELDING LEADS

ESAB Welding & Cutting Products

ELECTRODE HOLDER

Removable



Clamped

WORKPIECE CONNECTIONS

Figure 8-14. *Proper welding requires welding equipment such as welding leads, electrode holders, and workpiece connections.*

Welding Leads

Welding leads conduct current to and from the work. One lead runs from the welding machine to the electrode holder and the other is attached to the workpiece or the workbench. The lead connected to the electrode holder is called the electrode lead. The lead connected to the workpiece is called the workpiece lead or, incorrectly, the ground.

When the welding machine is ON and the electrode in the electrode holder comes in contact with the workpiece, a circuit is formed, allowing electricity to flow.

The correct diameter welding lead for the length of cable specified for the welding machine output must be used. If welding leads are too small for the current, they overheat and power is lost. Larger leads are needed to carry the required current long distances from the welding machine; otherwise, there will be an excessive voltage drop. With smaller diameter welding leads, the recommended length must not be exceeded because voltage drop across the leads lowers the efficiency of the welding. Check with the welding machine manufacturer for the proper welding lead sizes, and for specific lengths and usage.

All welding lead connections should be tight because loose connections cause the lug, lead, or clamp to overheat. A loose connection may also produce arcing at the connection. Welding leads should be kept clean and should be handled so as to avoid damage to the insulation.

Use properly sized welding leads to prevent voltage drop.

Keep welding leads orderly to prevent them from becoming a hazard. Fasten the welding leads overhead whenever possible. Never kink the welding leads.

Electrode Holders

An *electrode holder* is a handle-like tool that holds the electrode during welding. The electrode holder is attached to the electrode lead during welding. A properly designed electrode holder is essential to good welding.

Use an electrode holder that is completely insulated.

The jaws of the electrode holder must be properly insulated. Laying an electrode holder with uninsulated jaws on the workbench while the machine is running may cause a flash. A well-designed electrode holder can be identified by the following features:

- It is reasonably light, to reduce excessive fatigue while welding.
- It does not heat too rapidly.
- It is well balanced.
- It secures and releases electrodes easily.
- It is properly insulated.

Workpiece Connections

The workpiece connection must be fastened to the workpiece or the workbench to provide a complete path for the electrical circuit. A workpiece connection is attached to the workpiece lead to complete the circuit. This type of workpiece connection is removable, making it easier for a welder to change locations. A workpiece lead can be attached or welded to the workbench using the lug on the end of the lead. Connections should be made as close to the welding location as possible.

If welding near other workers, set up welding screens so the arc does not harm workers nearby.

SHOP TOOLS AND EQUIPMENT

Shop equipment, such as C-clamps, electrode ovens, tools, welding screens, and ventilation systems are required for a safe work area. See Figure 8-15. When welding workpieces that are too large to fit in a vise, C-clamps hold the workpieces in the proper position. Many electrodes must be stored at high temperatures to protect them from humidity. Electrode ovens maintain the required temperature and protect electrodes from damage. Floors should be constructed of fire-resistant materials and should be kept dry at all times to prevent possible shock.

Weld only in areas where there is adequate ventilation.

Work areas, walkways, ladders, etc. must be kept clear of obstructions. Welding equipment should not be positioned where it obstructs walkways or other work areas.

Tools

To produce a strong weld, the surface of the base metal must be free of foreign matter such as rust, oil, and paint. A wire brush (hand- or tool-powered) is used to clean metal surfaces.

After a bead is deposited on the metal, the slag that covers the weld is removed with a chipping hammer. The chipping operation is followed by additional wire brushing. Complete removal of slag is especially important when several passes must be made over a joint. If not removed, slag becomes trapped in the weld, and may form gas holes in the bead that result in porosity, which weakens the weld.

Welding Screen

Whenever welding is done in areas where other people may be working, the welding operation should be enclosed with screens so the ultraviolet rays cannot injure nearby workers. Welding screens can be easily constructed from fire-resistant canvas painted with black or gray ultraviolet-protective paint. When welding is done in a permanent location, a booth is desirable. A permanent welding booth provides the items needed to safely complete welding.

Ventilation System

Electrodes used for SMAW may emit a great deal of smoke and fumes, which should not be inhaled. The smoke and fumes are not harmful if the welding area is properly ventilated. There should be a suction fan or other adequate source of air circulation.

Permanent welding booths should be equipped with a sheet-metal hood with an extension arm mounted directly above the welding table and an exhaust system to draw out the smoke and fumes.

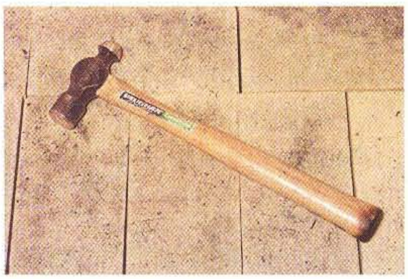
SMAW should not be performed without sufficient movement of air through the room. The general recommendation for adequate ventilation is a minimum of 2000 cu ft of air flow per minute per welding machine. If individual movable exhaust hoods can be placed near the work, the rate of air flow toward the hood

Shop Tools and Equipment
Figure 8-15

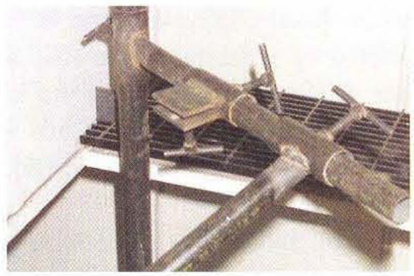
Osborn International

Hand Grinder

Chipping Hammers/ Wire Brushes

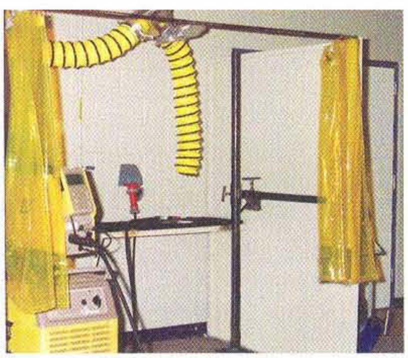


Ball Peen Hammer



Positioner

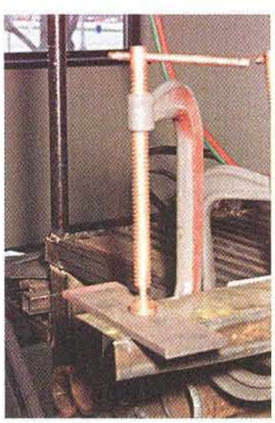
TOOLS



WELDING SCREEN

Nederman, Inc.

VENTILATION SYSTEM



C-CLAMP

ELECTRODE OVEN

Figure 8-15. *Shop tools and equipment assist the welder in maintaining a safe work environment and producing quality welds.*

Never look at a welding arc without wearing a welding helmet.

should be approximately 100 linear feet per minute in the welding zone. The exhaust hood should never be placed in a manner that draws the gas and fumes across the face of the welder.

PERSONAL PROTECTIVE EQUIPMENT

An electric arc not only produces a brilliant light, but also gives off invisible ultraviolet and infrared rays that are extremely dangerous to the eyes and skin. Additionally, extreme heat is generated by welding, as are slag and spatter, which may pop from the weld and strike a welder. Welders are required to wear personal protective equipment to prevent injury.

Safety glasses should be worn under face shields, hoods, and helmets, and at all times when working in the shop.

Approved work clothes, such as those made of leather, wool, or flame-resistant cotton; a headcap; safety glasses; approved work boots; and gloves are required for all welding and cutting operations. Light-duty welding requires cloth or leather gloves and a welding helmet with proper shading. Heavy-duty welding requires a leather jacket, leather gauntlet-type gloves, a leather apron, and a helmet with proper shading. See Figure 8-16.

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Figure 8-16. *Proper protective clothing must be worn to protect the welder from ultraviolet and infrared rays, and slag produced during welding.*

Coveralls or work clothing should prevent exposure of the skin to infrared and ultraviolet rays. Synthetic materials such as polyester should never be worn. Cuffs on pants should be turned down or eliminated and pockets removed to prevent molten metal from catching in the clothes. Sleeves and collars should be kept buttoned. Pant legs and shirt sleeves should be short enough that they do not bunch around the ankles or wrists.

The head and eyes must be protected from metal pieces or sparks that may be projected from a welding surface. Helmets with shaded lenses are required when performing any welding operations. Safety glasses should be worn under face shields, hoods, and helmets, and at all times when working in the shop. See Figure 8-17.

Eye Protection
Figure 8-17

Figure 8-17. *Eye protection must be worn at all times when working in the shop and during welding.*

POINTS TO REMEMBER

1. The heat used for SMAW is generated from an arc that develops when electricity jumps across an air/gas gap between the end of an electrode and the base metal. The air/gas gap produces high resistance to the current flow, generating intense heat.
2. Polarity affects the amount of heat directed to the workpiece. By changing polarity, heat can be concentrated where it is most needed.
3. The National Electrical Manufacturers Association (NEMA) has set a standard for duty cycle based on a 10 min period. The duty cycle standard expresses the actual operation time that a welding machine may be used at its rated load without exceeding the temperature limits of the insulation of the component parts.
4. Use properly sized welding leads to prevent voltage drop.
5. Keep welding leads orderly to prevent them from becoming a hazard. Fasten the welding leads overhead whenever possible. Never kink the welding leads.
6. Use an electrode holder that is completely insulated.
7. When welding near other workers, set up welding screens so the arc does not harm workers nearby.
8. Weld only in areas where there is adequate ventilation.
9. Never look at a welding arc without wearing a welding helmet.
10. Safety glasses should be worn under face shields, hoods, and helmets, and at all times when working in the shop.

QUESTIONS FOR STUDY AND DISCUSSION

1. What is an electrical circuit?
2. What is the difference between AC current and DC current?
3. What is polarity?
4. What determines whether the polarity of a welding machine is set for DCEN or DCEP?
5. What is voltage? What instrument is used to measure voltage?
6. What effect does welding polarity have on where heat is directed?
7. What is voltage drop? What effect does it have on welding current?
8. What is meant by open-circuit voltage and arc voltage?
9. What is meant by a constant-current welding machine?
10. What is a volt-amp curve?
11. Why is a transformer-rectifier often preferred for SMAW?
12. How are welding machines rated?
13. What is duty cycle when specifying welding machine ratings?
14. What are some of the requirements of an electrode holder?
15. Why is it important to weld only where there is adequate ventilation?

SMAW - Selecting Electrodes

9

Shielded Metal Arc Welding (SMAW)

There are many different types and sizes of electrodes, and the correct one must be selected to ensure a quality weld. In general, electrodes are classified into five types: mild steel, high-carbon steel, alloy steel, cast iron, and nonferrous. Most arc welding is done with electrodes in the mild steel group.

ELECTRODES

An *electrode* is a component of the welding circuit that conducts electrical current to the weld area. When current from a welding machine flows through the circuit to the electrode, an arc is formed between the end of the electrode and the work. The arc melts the electrode coating, electrode metal, and the base metal. The molten metal of the electrode flows into the crater and forms a solidified bond between the two pieces of metal being joined. As the weld solidifies, it forms a slag that slows the cooling rate of the deposited metal. See Figure 9-1.

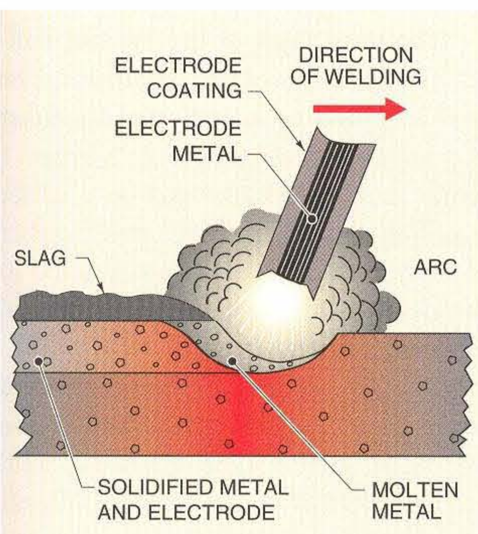


Figure 9-1. *Molten metal from the electrode flows into the crater, forming a solidified bond between the two pieces of metal. Slag is formed as the metal cools.*

Electrodes are manufactured to weld different metals, and are also designed specifically for DC or AC welding machines. A few electrodes work equally well on either DC or AC. Electrode usage also depends on the welding position. Some electrodes are best suited for flat position welding and horizontal fillet welding, while other types may be used in any position.

Some electrodes can only be used with DC welding machines and others can only be used with AC welding machines.

Mild steel electrodes are of two types: shielded or bare. Shielded electrodes have heavy coatings of various substances such as cellulose sodium, cellulose potassium, titania sodium, titania potassium, iron oxide, and iron powder, as well as several other ingredients. Each of the substances in the coating is intended to serve a particular function in the welding process, such as the following:

Use the correct type of electrode for the welding to be done.

- act as a cleaning and deoxidizing agent in the molten crater
- release carbon dioxide to protect the molten metal from atmospheric oxides and nitrides
- exclude oxygen and nitrogen because these contaminants weaken a weld if they come in contact with molten metal
- form a slag over the deposited metal that further protects the weld until the metal cools sufficiently to where it is no longer affected by

atmospheric contamination. The slag also slows the cooling rate of deposited metal, permitting the formation of a more ductile weld

- provide easier arc starting, stabilize the arc, and reduce spatter
- permit better penetration and improve the X-ray quality of the weld

Originally, bare electrodes were uncoated metal rods; today they are made with a coating. Bare electrodes are rarely used for welding because they are difficult to weld with and they produce brittle welds with low strength. Practically all welding is done with shielded electrodes.

The coating of some electrodes contains powdered iron, which converts to steel and becomes a part of the weld deposit. The powdered iron also helps to increase the speed of welding and improve the weld appearance.

Low-hydrogen electrodes have coatings that are high in limestone and other ingredients with a low hydrogen content, such as calcium fluoride, calcium carbonate, magnesium-aluminum silicate, and ferrous alloys. Low-hydrogen electrodes are used to weld high-sulfur and medium- or high-carbon steels that have a great affinity for hydrogen. Low-hydrogen electrodes must be used because these steels react with hydrogen, causing underbead cracking in welds in the heat-affected zone (HAZ) adjacent to the weld.

Identifying Electrodes

Electrodes are referred to by manufacturer trade name and by American Welding Society (AWS) classification. These classifications were set up by AWS to establish requirements for electrodes and to ensure uniformity among manufacturers. Electrodes from different manufacturers, if they are in the same AWS classification, should have similar welding characteristics. Most electrodes manufactured in the United States are imprinted with an AWS symbol. See Figure 9-2.

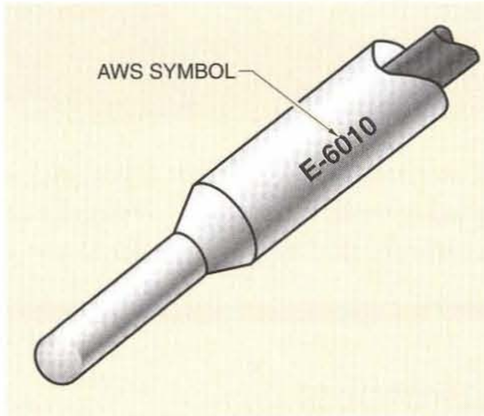


Figure 9–2. *The American Welding Society (AWS) numerical electrode classification identifies the characteristics and usage of the electrode.*

AWS classifications assign each type of electrode a specific symbol, such as E-6010, E-6012, or E-7018. The prefix E identifies an electrode for electric arc welding. The first two digits in the symbol designate the minimum allowable tensile strength of the deposited weld metal in thousands of pounds per square inch (psi). For example, the 60 series electrodes have a minimum tensile (pull) strength of 60,000 psi; the 70 series, a strength of 70,000 psi.

The third digit of the symbol indicates possible welding positions. The welding position is indicated by either a number 1 or a number 2. Number 1 is for an electrode that can be used for welding in any position, and number 2 represents an electrode restricted to welding in flat position and horizontal position fillet welds only.

The fourth digit of the symbol shows special characteristics of the electrode, such as type of coating, weld quality, type of arc, or amount of penetration. The fourth digit may be any digit between 0 and 8. Because the welding position depends on the

manufacturer characteristics of the electrode coating, the third and fourth digits are often viewed together. The fourth-digit values in the AWS electrode classification system are:

E-XXX0. DCEP. Produces high-quality deposits with deep penetration and flat or concave beads. Cellulose sodium coating.

E-XXX1. DCEP or AC. Produces high-quality deposits with deep penetration and flat to slightly concave beads. Cellulose potassium coating.

E-XXX2. DCEN or AC. Medium-quality deposits, medium arc, medium penetration, and convex beads. Titania sodium coating.

E-XXX3. DCEP, DCEN, or AC. Medium- to high-quality deposits, soft arc, shallow penetration, and slightly convex beads. Titania potassium coating.

E-XXX4. DCEP, DCEN, or AC. Fast deposition rate; deep-groove, fillet, and lap welds; medium penetration; easy slag removal. Iron powder, titania coating.

E-XXX5. DCEP. High-quality deposits, soft arc, moderate penetration, flat to slightly convex bead, low hydrogen content in weld deposits. Low-hydrogen sodium coating.

E-XXX6. DCEP or AC. High-quality deposits, soft arc, moderate penetration, flat to slightly convex bead, low hydrogen content in weld deposits. Low-hydrogen potassium coating.

E-XXX7. DCEN or AC. Fast fill, fast deposition rate, medium penetration, low spatter, flat beads. Iron powder, iron oxide.

E-XXX8. DCEP or AC. Fill-freeze, shallow to medium penetration, high deposition, easy slag removal, convex beads. Iron powder, low-hydrogen.

An additional letter-number combination may also come after the four-digit classification number. An H4 indicates a hydrogen level of less than 4 ml/100g of electrode. H8 indicates a hydrogen level of less than 8 ml/100g of electrode. The letter R may follow the hydrogen level if the electrode meets the requirements of the absorbed moisture test. See Figure 9-3.

For mild steel, the complete classification number E-6010 would signify an electrode that (a) has a minimum tensile strength of 60,000 psi for the as-welded deposited weld metal, (b) is usable in all welding positions, and (c) can be used with DCEP only. Similarly, E-7024 designates an electrode that (a) has a minimum tensile strength of

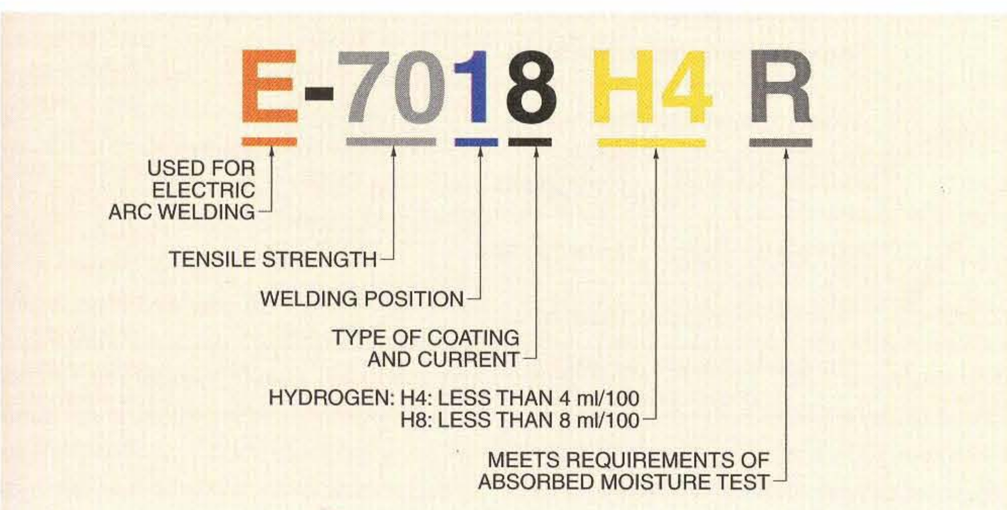


Figure 9–3. *The electrode identification uses a letter and numbers combination to identify the electrode characteristics.*

70,000 psi, (b) is usable for welding in flat position and horizontal position fillet welds only, and (c) operates on DCEP, DCEN, or AC and has an iron powder coating. The fourth digit cannot be considered individually; it must be associated with the third digit since together, the third and fourth the digits identify the polarity and position of the electrode. See Figure 9-4.

In the past, some electrodes were identified using a color code established by the National Electrical Manufacturers Association (NEMA). This identification code is no longer used except for some surfacing electrodes.

Selecting Correct Electrodes

The ideal electrode is one that provides good arc stability, a smooth weld bead, fast deposition, minimum spatter, maximum weld strength, and easy slag removal. To achieve these characteristics, seven factors should be considered in selecting an electrode—base metal properties, electrode diameter, joint design and fit-up, welding position, welding current and polarity, production efficiency, and service conditions.

Base Metal Properties. A weld should be at least as strong as the base metal. The electrode used must produce a weld metal with approximately the same mechanical properties as the base metal.

Electrodes are available for welding different classifications of metal. Some electrodes are designed to weld carbon steels, others are best suited for low-alloy steels, and some are intended specifically for special purpose alloy steels such as chrome-moly. Therefore, before any welding operation, the first consideration is to check the chemical analysis of the metal and then select an electrode that is recommended for that metal. Never weld on an unidentified metal.

ELECTRODE IDENTIFICATION

AWS Classification	Position*	Weld Characteristics†	Weld Current†	Coating†
EXX 10	ALL	Deep penetration, flat or concave beads	DCEP	Cellulose sodium
EXX 20	FLAT, HORIZONTAL			
EXX 11	ALL	Deep penetration, flat or concave beads	DCEP, AC	Cellulose potassium
EXX 12	ALL	Medium penetration, convex beads	DCEN, AC	Titania sodium
EXX 13	ALL	Shallow penetration, convex beads	DCEP, DCEN, AC	Titania potassium
EXX 14	ALL	Medium penetration, fast deposit	DCEP, DCEN, AC	Iron powder titania
EXX 24	FLAT, HORIZONTAL			
EXX 15	ALL	Moderate penetration, convex beads	DCEP	Low-hydrogen sodium
EXX 16	ALL	Moderate penetration, convex beads	DCEP, AC	Low-hydrogen potassium
EXX 27	FLAT, HORIZONTAL	Medium penetration, flat beads	DCEP, DCEN, AC	Iron powder iron oxide
EXX 18	ALL	Shallow to medium penetration, convex beads	DCEP, AC	Iron powder low-hydrogen
EXX 28	FLAT, HORIZONTAL			

* 3RD number of AWS classification
† 4TH number of AWS classification

Figure 9–4. *The third and fourth digits in the electrode classification identify the proper welding position and the weld characteristics of the electrode.*

Electrode Diameter. Generally, the diameter of the electrode should not be larger than the thickness of the metal to be welded. Some welders prefer larger electrodes because they permit faster travel along the joint and thus speed up the welding operation, but this requires considerable skill.

It takes approximately half the time to deposit a quantity of weld metal from 1/4″ coated mild steel electrodes than 3/16″ mild steel electrodes. The larger sizes not only make higher current use possible, but require fewer stops to change the electrode. For economy, the largest possible electrode diameter should be used that is practical for the work at hand.

When making vertical or overhead welds, 3/16″ is the largest diameter electrode that should be used regardless of the base metal thickness. Larger electrodes make it too difficult to control the deposited metal. Ordinarily, a fast-freeze electrode is best for vertical and overhead welding.

The diameter of the electrode is also influenced by joint design. On thick metal with a narrow root, a small-diameter electrode is used to deposit the root bead to ensure thorough penetration at the root of the weld. Successive passes are then made with larger diameter electrodes, if necessary.

Joint Design and Fit-Up. Joints with insufficiently beveled edges require deep-penetrating, fast-freeze electrodes. This type of electrode has a digging characteristic and may require more skillful electrode manipulation by the welder. Joints with open gaps need a mild, penetrating, fill-freeze electrode that rapidly bridges gaps.

Welding Position. The position of the weld joint must be considered when selecting an electrode. Some electrodes produce better results when welding is done in flat position. Other electrodes are designed for vertical, horizontal, and overhead welding. See Figure 9-5.

Figure 9–5. *The electrode selected must be matched to the position of the weld joint.*

Welding Current and Polarity. Electrodes are specified for DCEP, DCEN, or AC current, although some electrodes work with AC or DC current. To minimize polarity confusion, manufacturers now designate straight polarity electrodes as DCEN and reverse polarity electrodes as DCEP.

If welding is to be done on a DC welding machine, check whether DCEN or DCEP is needed for the particular electrode to be used.

Production Efficiency. Deposition rate is important in production work. The faster a weld can be made, the lower the cost. Not all electrodes have a high-speed, high-current rating with the ability to produce smooth, even bead ripples. Unless electrodes are noted for a fast deposition rate, they may prove very difficult to handle when used at high-speed travel.

Service Conditions. The service requirements of the part being welded may demand special weld deposits. For example, high corrosion resistance, ductility, or high strength may be important factors. In such cases, electrodes must be selected that will produce these specific characteristics.

Conserving and Storing Electrodes

Most electrodes are costly; therefore, consume as much of the electrode as possible. Do not discard stub ends until they are down to 1½″ to 2″ long. See Figure 9-6.

Use an electrode until the stub is no longer than 1½″ to 2″.

Store electrodes in a dry place, at normal room temperature, with a 50% maximum relative humidity. When exposed to moisture, the coating tends to disintegrate.

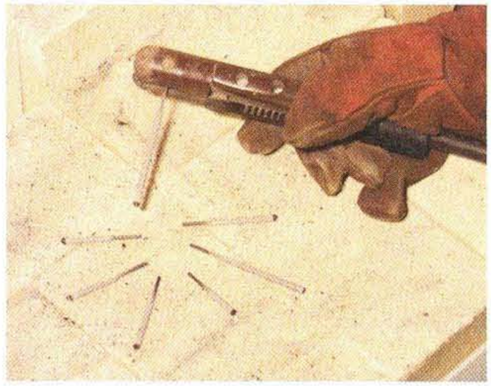


Figure 9-6. *Use electrodes until the stubs have been consumed down to 1½″ to 2″ long.*

Store electrodes in a dry place where the coating cannot be damaged.

Low-hydrogen electrodes are especially vulnerable to moisture. Low-hydrogen electrodes, such as E-7018, after being removed from their moistureproof container, should be stored in heated drying ovens at 250°F to 300°F. Stationary and portable drying ovens are often used for storing electrodes at specified holding temperatures. Low-hydrogen electrodes should be stored separately from other types of electrodes. When storing any type of electrode, do not bump, bend, or step on the electrodes. Damaged or chipped electrodes are useless and must be discarded.

ELECTRODE CLASSIFICATION

Electrodes can be classified by type as mild steel, iron powder, and low-hydrogen. See Figure 9-7. Electrodes are commonly grouped as fast-freeze, fill-freeze, and fast-fill.

A *fast-freeze electrode* is an electrode that produces a snappy, deep-penetrating arc and fast-freezing deposit. Fast-freeze electrodes produce little slag and flat beads. They are used for all-position welding for fabrication and repair work. They are preferred for vertical and overhead position.

ELECTRODE CLASSIFICATIONS

AWS Class	Current Type	Welding Position	Weld Results	Electrode Group
E-6010	DCEP	ALL	Deep penetration, flat beads	Fast-freeze
E-6011	DCEP, DCEN, AC			
E-6012	DCEN AC	ALL	Shallow penetration, good bead contour, minimum spatter, for poor fit-up	Fill-freeze
E-6013	DCEP, DCEN, AC			
E-6020	DCEP DCEN AC	FLAT, HORIZONTAL	High deposition, deep groove single-pass welds	Fast-fill
E-6027	DCEN AC	FLAT, HORIZONTAL	High deposition, deep penetration	Fast-fill
E-7014	DCEP DCEN AC	ALL	Low penetration, high speed	Fill-freeze
E-7024	DCEP DCEN AC	FLAT, HORIZONTAL	High deposition, single and multiple passes	Fast-fill
E-7016	DCEP AC	ALL	Welding of high-sulfur and high-carbon steels that tend to develop porosity and crack under weld bead	Fill-freeze
E-7018	DCEP AC	ALL		
E-7028	DCEP AC	FLAT, HORIZONTAL		Fast-fill

DCEP–direct current electrode positive
DCEN–direct current electrode negative
AC–alternating current

Figure 9-7. *AWS classes of electrodes can be further categorized by type, such as mild steel, iron powder, and low-hydrogen, each including several AWS classifications and having certain welding characteristics.*

A *fill-freeze electrode* is an electrode that has a moderately forceful arc and deposit rate. The arc and deposit rates are between those of the fast-freeze and fast-fill electrodes. Fill-freeze electrodes have complete slag coverage and weld beads with distinct, even ripples. They are a general-purpose electrode for production shops and are particularly useful for repair work and joints with poor fit-up. They can be used in all positions, though they are not recommended for vertical and overhead welding.

A *fast-fill electrode* is an iron powder electrode that has a soft arc and fast deposit rate. These electrodes have a heavy slag and produce exceptionally smooth weld beads. They are generally used for production welding where all work can be performed in flat position.

Mild Steel Electrodes

The most commonly used mild steel electrode is E-6010, because of its penetration and fast-freeze capabilities. The current settings for mild steel electrodes are determined by the size of the electrode. Commonly used mild steel electrodes include E-6010, E-6011, E-6012, and E-6013. See Figure 9-8.

E-6010. The E-6010 electrode is an all-position, fast-freeze electrode. It is suitable only with DCEP, and is designed primarily for welding mild and low-alloy steels. It should be used only where there is good fit-up. The E-6010 electrode has wide applications in ship construction, buildings, bridges, tanks, and piping.

E-6011. The E-6011 electrode is similar to the E-6010 except that it can also be used on AC welding machines. Although the electrode can be used with DCEP, it does not work quite as well as the E-6010. Its current setting is slightly lower than for the E-6010.

MILD STEEL ELECTRODE CURRENT SETTINGS

Electrode	Diameter*	Amperes†
E-6010	3/32	60 – 90
	1/8	80 – 120
	5/32	110 – 160
	3/16	150 – 200
	7/32	175 – 250
	1/4	225 – 300
	5/16	250 – 450
E-6011	3/32	50 – 90
	1/8	80 – 130
	5/32	120 – 180
	3/16	140 – 220
	7/32	170 – 250
	1/4	225 – 325
E-6012	3/32	40 – 90
	1/8	80 – 120
	5/32	120 – 190
	3/16	140 – 240
	7/32	180 – 315
	1/4	225 – 350
E-6013	1/16	20 – 40
	5/64	25 – 50
	3/32	30 – 80
	1/8	80 – 120
	5/32	120 – 190
	3/16	140 – 240
	7/32	225 – 300
	1/4	50 – 350

* in in.
† ranges may vary depending on manufacturer

Figure 9-8. *Mild steel electrodes are used for many general welding operations, and current settings vary depending on the size of the electrode.*

E-6012. The E-6012 electrode is a fill-freeze electrode that may be used on either DC or AC welding machines. When it is used on DC welding machines, the current must be set for electrode negative. An E-6012 electrode provides medium penetration, a quiet arc, slight spatter, and dense slag. Although it is considered an all-position electrode, it is more commonly used for flat and horizontal position welds. This electrode is especially useful for bridging gaps on work with poor fit-up. Higher currents can be used with the E-6012 electrodes than with any other type of all-position electrode.

E-6013. The E-6013 electrode is similar to the E-6012, with a few exceptions. With the E-6013, slag is removed easily and the arc can be maintained more easily, especially with small-diameter electrodes, permitting better

operation with lower open-circuit voltage. The bead deposited is noticeably flatter and smoother but has shallower penetration than the E-6012 electrode. Although the E-6013 electrode is used particularly for welding sheet metal, it has many other applications. It works well in all positions and it functions best with AC welding machines. When used with DC welding machines, electrode positive or electrode negative may be used.

Iron Powder Electrodes

Iron powder electrodes are those that contain a high iron powder content. Iron powder electrodes are designed for welding mild steel where high speed and fast deposition rate are required. The three principal types of iron powder electrodes are E-6027, E-7014, and E-7024, all of which produce low spatter with easy slag removal. Typical applications include railroad cars; earth-moving equipment; positioned welds in pressure vessels; piping; and ships. The E-7014 and E-7024 are often used where higher strength joints are necessary. See Figure 9-9.

Hobart Welders

Electrodes are designed to meet a range of welding needs. Selection should be based on the characteristics of the metal to be welded.

IRON POWDER ELECTRODE CURRENT SETTINGS

Electrode	Diameter*	Amperes†
E-6027	3/16	225 – 300
	7/32	275 – 375
	1/4	350 – 450
E-7014	3/32	80 – 110
	1/8	110 – 150
	5/32	140 – 190
	3/16	180 – 260
	7/32	250 – 325
	1/4	300 – 400
	5/16	400 – 500
E-7024	3/32	90 – 120
	1/8	120 – 150
	5/32	180 – 230
	3/16	250 – 300
	7/32	300 – 350
	1/4	350 – 400
	5/16	400 – 500

* in in.
† ranges may vary depending on manufacturer

Figure 9-9. *Iron powder electrodes have various current settings, depending on size, and are commonly used for joints requiring high weld strength.*

E-6027. The E-6027 electrode produces high-quality welds for high-speed deposition of 1/4″ and 5/16″ horizontal fillets; for groove and fillet welds in the flat position; and for cover passes on groove welds where complete coverage and good bead appearance are required. DCEN or AC may be used. A drag welding technique is recommended to keep the cover over both legs of fillet welds.

E-7014. The E-7014 electrode is a fast-fill or fast-freeze electrode used when high speed is necessary. E-7014 electrodes may be used in all positions with DCEP, DCEN, or AC. The E-7014 electrode deposits much more metal than an E-6012 or E-6013 type. It is particularly effective in downhill welding.

E-7024. The E-7024 electrode is a fast-fill electrode that is exceptionally economy for single- or multiple-pass welds. It is also excellent for buildup applications because of its high deposition rate and easy slag removal. The E-7024 is recommended only for flat and horizontal positions, but can be used with DCEP, DCEN, or AC.

Low-Hydrogen Electrodes

Low-hydrogen electrodes are designed for welding high-sulfur and medium- or high-carbon steels. When such steels are welded, they tend to develop cracks under the weld bead because of hydrogen absorption from arc atmospheres. Low-hydrogen electrodes were developed to prevent the introduction of hydrogen into the weld and HAZ adjacent to the weld. Basic low-hydrogen electrodes are E-7016, E-7018, and E-7028. The most commonly used low-hydrogen electrode is E-7018 because of its fast-fill capability, reduced cracking on heavy sections, good appearance, and ability to be used to weld high carbon steels. See Figure 9-10.

E-7016. The E-7016 electrode is an all-position electrode suitable for AC or DCEP. It is especially recommended for welding hardenable steels where no preheat is used, and where stress relieving normally would be required but cannot be performed.

LOW-HYDROGEN ELECTRODE CURRENT SETTINGS		
Electrode	Diameter*	Amperes†
E-7016	3/32	75 – 105
	1/8	100 – 150
	5/32	140 – 190
	3/16	190 – 250
	7/32	250 – 300
	1/4	300 – 375
E-7018	3/32	70 – 120
	1/8	100 – 150
	5/32	120 – 200
	3/16	200 – 275
	7/32	275 – 350
	1/4	300 – 400
E-7028	5/32	175 – 250
	3/16	250 – 325
	7/32	300 – 400
	1/4	375 – 475

* in in.
† ranges may vary depending on manufacturer

Figure 9–10. *Low-hydrogen electrodes are recommended for steels with high-sulfur and high-carbon contents. Current settings depend on the size of the electrode.*

ESAB Welding & Cutting Products

Selecting the proper electrode ensures that a quality weld can be produced.

E-7018. The E-7018 electrode is a low-hydrogen electrode, but it also contains iron powder. It is a high-speed, fast-deposition-rate electrode designed to pass the most severe X-ray requirements when applied in all welding positions, using either AC or DCEP. Its weld pool fluidity permits gases to escape when the lowest currents are used for out-of-position welding.

E-7028. The E-7028 electrode is a low-hydrogen electrode with a heavy iron powder covering. The E-7028 is considered the counterpart of the E-7018, but it is recommended for flat and horizontal positions only.

VARIABLES OF SELECTING ELECTRODES

Variables normally associated with most types of welding include deposition rate; depth of penetration; appearance and undercutting; soundness, ductility, and low-impact strength of the weld, degree of spatter; quality of fit-up required; welder appeal; and degree of slag removal. Additionally, the type of metal to be welded, such as thin metal, heavy steel, or high-sulfur or off-analysis steel, is a determinant in the type of electrode to use. See Figure 9-11.

ELECTRODE SELECTION CHART*											
Variables	Electrode Class†										
	E6010	E6011	E6012	E6013	E6027	E7014	E7024	E7016	E7018	E7028	E6020
Groove butt welds, flat (< ¼″)	5	5	3	8	10	9	9	7	9	10	10
Groove butt welds, all positions (< ¼″)	10	9	5	8	(b)	6	(b)	7	6	(b)	(b)
Fillet welds, flat or horizontal	2	3	8	7	9	9	10	5	9	9	10
Fillet welds, all positions	10	9	6	7	(b)	7	(b)	8	6	(b)	(b)
Current (C)‡	DCEP	DCEP AC	DCEN AC	DC AC	DC AC	DC AC	DC AC	DCEP AC	DCEP AC	DCEP AC	DC AC
Thin material (¼″)	5	7	8	9	(b)	8	7	2	2	(b)	(b)
Heavy plate or highly restrained joint	8	8	8	8	8	8	7	10	9	9	8
High-sulfur or off-analysis steel	(b)	(b)	5	3	(b)	3	5	9	9	9	(b)
Deposition rate	4	4	5	5	10	6	10	4	6	8	6
Depth of penetration	10	9	6	5	8	6	4	7	7	7	8
Appearance, undercutting	6	6	8	9	10	9	10	7	10	10	9
Soundness	6	6	3	5	9	7	8	10	9	9	9
Ductility	6	7	4	5	10	6	5	10	10	10	10
Low-temperature impact strength	8	8	4	5	9	8	9	10	10	10	8
Low spatter loss	1	2	6	7	10	9	10	6	8	9	9
Poor fit-up	6	7	10	8	(b)	9	8	4	4	4	(b)
Welder appeal	7	6	8	9	10	10	10	6	8	9	9
Slag removal	9	8	6	8	9	8	9	4	7	8	9

* Rating is on a comparative basis of same-size electrodes with 10 as the highest value. Ratings may change with size
† AWS
‡ DCEP–direct current electrode positive; DCEN–direct current electrode negative; AC–alternating current; DC–direct current, either polarity
(b) Not recommended

Figure 9–11. *Electrodes are rated based on their suitability to the different conditions to which they will be subjected.*

Although there are a variety of electrode classification charts that list the basic characteristics or differences in electrodes, many of the variables encountered in production often require testing to determine the suitability of an electrode for a specific application. By first analyzing the variables in terms of their importance in a welding situation, considerable time and effort can be saved. The suitability of an electrode for use with certain types of joints, such as groove butt welds and fillet welds, can be rated to help determine the proper electrode to use.

The variables have a relative rating ranging from 1 to 10, with 10 as the highest value and 1 the lowest. These variables and their corresponding ratings are based on experience and are intended primarily as an aid in the electrode selection process. For example, if high-sulfur steel is to be welded, either E-7016 or E-7018 electrodes should be used.

If poor fit-up is the problem, electrode E-6012 is considered the best electrode. If the deposition rate is the primary factor, then either E-6027 or E-7024 is the most suitable.

Special Electrodes

Special electrodes are used for specific applications, on specific materials, to obtain particular surface characteristics, or for health and environment reasons. For example, some electrodes are environmentally safe and emit no radiation or radioactive gases; release no contamination to the atmosphere; and produce no contamination during grinding or machining. Some special electrodes require very little heat input.

Special electrodes are used to allow welding of certain materials, to improve welding time and quality in specific applications such as underwater, extreme heat, extreme cold, or where the surface to be welded cannot be completely cleaned of dirt, paint, or other material. Welding operations such as surfacing and gouging are possible using special electrodes.

A variety of special electrodes are available to meet the particular welding requirements of metals such as aluminum, cast iron, nickel, copper, magnesium, titanium, alloy metals, and tool steels. Special electrodes prevent cracking and embrittlement and may allow dissimilar metals to be welded.

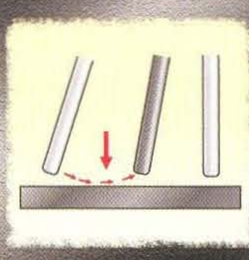
Special electrodes can be used to build up a base metal surface to allow machining, or to harden the weld for grinding. Special electrodes can also add corrosion resistance to a weld and allow a weld to be galvanized.

POINTS TO REMEMBER

1. Use the correct type of electrode for the welding to be done.
2. Some electrodes can only be used when welding with DC current; others are only used with AC current.
3. If welding is to be done using DC current, determine whether DCEN or DCEP is needed for the particular electrode to be used.
4. Select an electrode with a diameter that is about one-half the thickness of the metal to be welded.
5. Use an electrode until the stub is no longer than 1½″ to 2″.
6. Store electrodes in a dry place where the coating cannot be damaged.

QUESTIONS FOR STUDY AND DISCUSSION

1. What is the difference between bare and shielded electrodes?
2. Why are bare electrodes rarely used?
3. What are the functions of the heavy coating on shielded electrodes?
4. What has been done to ensure uniformity of electrode specifications?
5. What symbols have been adopted to identify different types of electrodes?
6. Explain the identifying symbols of the electrode classification E-6010.
7. What is an all-position electrode?
8. How can the current and polarity an electrode is designed for be determined?
9. What factors should be taken into consideration when selecting an electrode for a job?
10. Why are smaller diameter electrodes used for overhead welding?
11. What precautions must be taken in storing electrodes?
12. What is the specific feature of electrodes with coatings containing powdered iron?
13. Why are low-hydrogen electrodes used?
14. What are some of the specific characteristics of electrodes designated as fast-freeze?
15. Some electrodes are classified as fill-freeze. What does this mean?
16. For what types of welding are fast-fill electrodes intended?
17. What is the function of slag in the welding process?
18. How does joint design affect the diameter of the electrode used?
19. What organization is responsible for establishing a standard numerical electrode classification?
20. Which electrodes provide deep penetration?



SMAW – Striking an Arc 10

Shielded Metal Arc Welding (SMAW)

SMAW requires mastery of a specific series of operations through practice. Once these skills have been acquired, they can be applied on any welding job. The first basic SMAW operation is learning to strike an arc and deposit a straight bead.

BASIC PRINCIPLES OF SUSTAINING A WELDING ARC

The success of any welding operation depends upon a stable arc. See Figure 10-1. To sustain a stable arc, four basic elements are necessary:

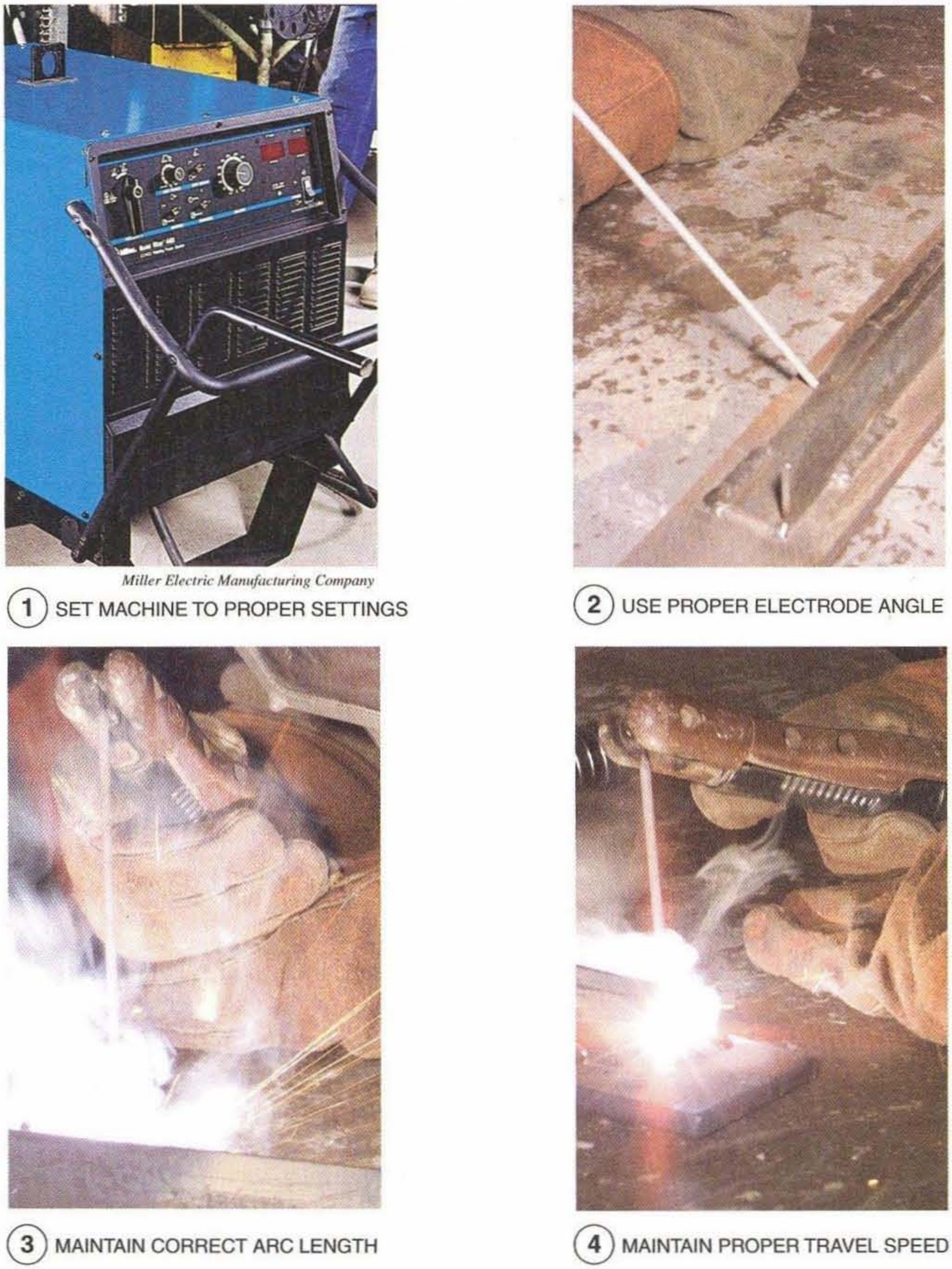
- Machine setting. The welding machine must be adjusted to the required current setting. Current is the flow of electricity (electrons) and is regulated by a control on the welding machine. The current used depends on the size and type of electrode used, the position of the weld, and the base metal. The machine setting also depends on the design of the welding machine.
- Electrode angle. *Electrode angle* is the angle at which the electrode is held during the welding process. Using the correct electrode angle ensures proper penetration and bead formation. As different positions and weld joints become necessary, the electrode angle becomes increasingly important in obtaining a satisfactory weld.
- Arc length. A proper arc length, of approximately 1/8″, between the electrode and the work is essential to generate the heat needed for welding. An arc that is too long produces an unstable welding arc, reduces penetration, increases spatter, causes flat and wide beads, and prevents the gas shield from protecting the molten pool from atmospheric contamination. If too short an arc is used, the arc does not create enough heat to melt the base metal, the electrode has a tendency to stick, penetration is poor, and uneven beads with irregular ripples result.
- Travel speed. *Travel speed* is the rate at which the electrode is moved along the weld joint. Factors such as size and type of electrode, current, weld position, and base metal affect the speed of travel necessary for completing a sound weld.

Miller Electric Manufacturing Company

A stable arc is maintained during welding to ensure the required weld characteristics.

Figure 10-1. *Proper machine settings, electrode angle, arc length, and travel speed are necessary in order to sustain an arc during welding.*

Sustaining a Welding Arc
Figure 10-1



Inspect the equipment before starting to weld.

Set the polarity switch to the recommended position.

Checking and Adjusting Equipment

Equipment for SMAW includes a welding machine, electrode, electrode holder, electrode lead, workpiece lead, and workpiece connection. See Figure 10-2. Equipment must be checked regularly to ensure quality welding. To start the welding operation, follow the procedure:

1. Inspect the lead connections to make certain they are tight.
2. Make sure the bench top and base metal to be welded are dry and free from dirt, rust, and grease.
3. Select the proper polarity.
4. Adjust the welding machine control unit for the current needed for the selected electrode.

SMAW Equipment
Figure 10-2

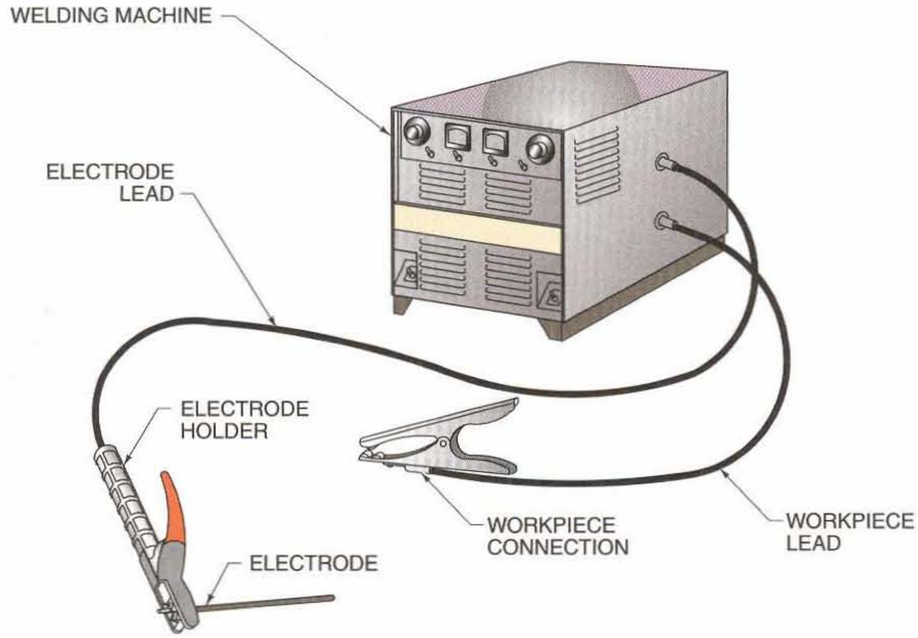


Figure 10-2. *Equipment for SMAW includes a welding machine, electrode, electrode holder, electrode lead, workpiece lead, and workpiece connection.*

Gripping the Electrode

Place the bare end of the electrode in the electrode holder. See Figure 10-3. By gripping the electrode near the end, most of the coated portion can be used. Keep the jaws of the electrode holder clean to ensure good electrical contact with the electrode.

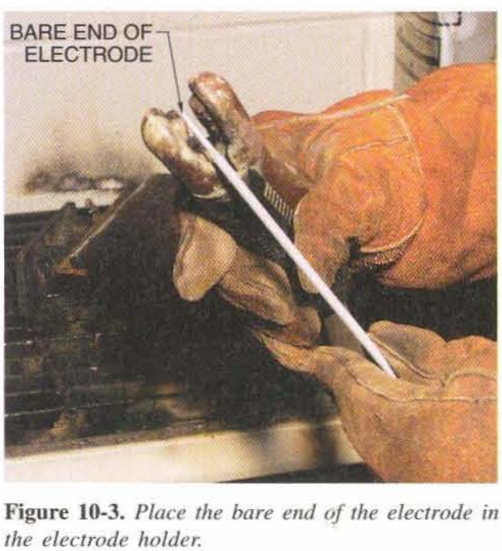


Figure 10-3. *Place the bare end of the electrode in the electrode holder.*

Do not touch the welding bench with an uninsulated electrode holder, as this causes a flash. When not in use, hang the electrode holder in the place provided for it. Grip the electrode holder lightly in the hand. If the electrode holder is held too tightly, the hand and arm will tire quickly.

Do not lay the electrode holder on the bench while current is flowing.

Adjusting the Current

The recommended current setting specified for the electrode is only approximate. Final adjustment of the current value is made after beginning the welding operation. For example, the current range for the electrode may be 90 A to 100 A. Before starting to weld, set the current control midway between the two limits, which in this case is 95 A. Once the welder is able to strike an arc and run short weld beads, the welding current should be varied to see how it affects the welding heat.

Release the electrode if it sticks to the workpiece.

CAUTION

Keep combustible materials away from the welding area, as flying sparks and spatter may ignite flammable materials.

Start with the recommended current range and adjust the current as necessary after welding begins.

Always shut OFF the welding machine when leaving the welding bench.

Turn the current down about 5 A and check for any differences when depositing a bead. Then turn it down another 5 A and again try to run a bead. As the current is reduced, it becomes apparent that there is insufficient heat to melt the base metal.

Furthermore, as the electrode burns off, it does not fuse with the base metal but lies on the surface as spatter, which easily scrapes off after welding.

Reverse the process by gradually raising the current. Turn the machine up 5 A in several steps and each time run short beads. As the current is increased, the arc gets hotter and the electrode melts faster.

No specific rules can be given for the final current setting because many factors are involved, such as the skill of the welder, welding position, type of metal, and nature of the welding job. The ability to make the final adjustment comes with experience.

Arc welding equipment must be installed and grounded, with the necessary disconnects, fuses, and incoming power lines, in accordance with requirements of ANSI/NFPA 70, the National Electrical Code®, *and relevant local codes.*

POINTS TO REMEMBER

1. Inspect the equipment before starting to weld.
2. Set the polarity switch to the recommended position.
3. Do not lay the electrode holder on the bench while current is flowing.
4. Release the electrode if it sticks to the workpiece.
5. Start with the recommended current range and adjust the current as necessary after welding begins.
6. Always shut OFF the welding machine when leaving the welding bench.

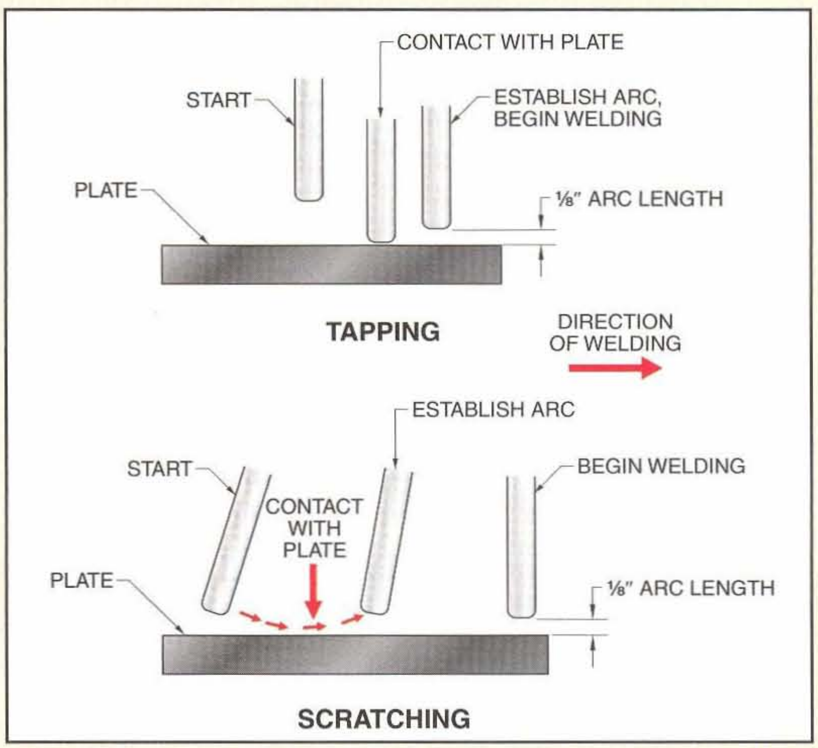
Exercises

Striking the Arc

exercise 1

1. Obtain a piece of 1/4″ mild steel.
2. Position the workpiece in flat position.
3. Use 1/8″ or 5/32″; E-6012, E-6013, or E-7024 electrode. Insert the electrode in the electrode holder and set the welding machine for the correct current.
4. Two methods can be used to strike the arc—the tapping method and the scratching method. The tapping method is preferred by experienced welders; however, the scratching method is easier.

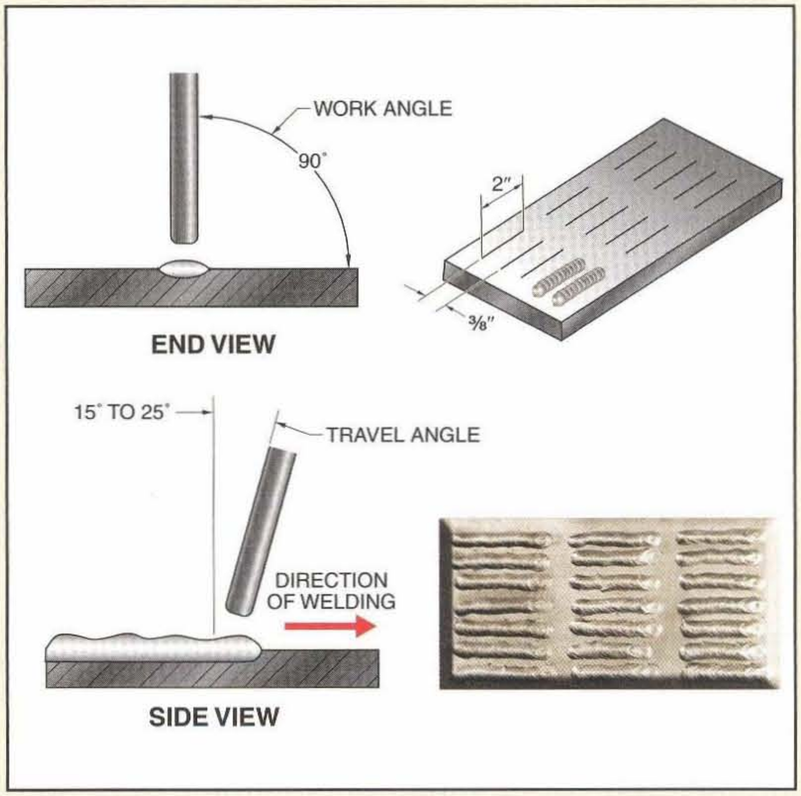
   In the tapping method, the electrode is brought straight down to contact the workpiece and is withdrawn instantly. With the scratching method, the electrode is moved at an angle in contact with the workpiece in a scratching motion, much like striking a match. Regardless of the motion used, upon contact with the workpiece, promptly raise the electrode a distance equal to the diameter of the electrode; otherwise, the electrode will stick to the workpiece. If allowed to stick with the current flowing, the electrode becomes red hot. Should the electrode weld fast to the workpiece, break it loose by quickly twisting or bending the electrode holder. If it should fail to dislodge, disengage the electrode by releasing it from the electrode holder.
5. Practice striking an arc until the operation can be performed quickly and easily.



Depositing Short Weld Beads

exercise 2

1. Obtain a piece of mild steel.
2. With a soapstone, draw a series of lines on the workpiece, each line approximately 2″ in length and 3/8″ apart.
3. Position the workpiece so the lines are in flat position.
4. Deposit a continuous bead over each line, moving the electrode from left to right. Hold the electrode in a vertical position and angle the electrode holder slightly toward the end of the weld. This is the travel angle.



5. Move the electrode just rapidly enough so deposited metal has time to penetrate into the workpiece. If the current is set properly and the arc is maintained at the correct length, there will be a continuous crackling or frying noise. An arc that is too long makes a humming sound. Too short of an arc makes a popping sound. Notice the action of the molten weld pool and how the trailing edge of the weld pool solidifies as the electrode travels forward.

   The appearance of the weld pool is an indication of how well a weld is being made. If the molten metal is clear and bright, it means that no molten slag is mixing with the weld pool. Slag is brittle and when it flows in the molten metal the weld is weakened. Normally, if the edges of the weld bead have a dull, irregular appearance, it means that slag is being trapped in the weld pool.

QUESTIONS FOR STUDY AND DISCUSSION

1. How does arc length affect a weld?
2. Why must the current be adjusted for a particular welding operation?
3. What equipment checks are made before proceeding to weld?
4. Why should the electrode be clamped at its extreme end?
5. Why should the electrode holder never be placed on the workbench while the current is ON?
6. What two methods may be used in striking an arc?
7. When striking an arc, why should the electrode be withdrawn instantly?
8. What should be done if the electrode welds fast to the plate?
9. The arc should be maintained at approximately what length?

SMAW – Depositing a Continuous Bead 11

Shielded Metal Arc Welding (SMAW)

To produce a quality weld, a welder must be able to manipulate the electrode and understand certain weld characteristics. A welder must be knowledgeable about factors that contribute to good quality and poor quality welds. Quality welds are produced by using the correct welding procedures, properly cleaning the weld, and preventing contamination of the weld.

ESSENTIALS OF ARC WELDING

The characteristics of the electrode must be known to ensure that the proper electrode is selected for each welding operation. The electrode must also be able to maintain its metal properties after deposition. Without the proper electrode, it is almost impossible to achieve the desired results, regardless of the welding technique used. As welding is performed, the heat from the arc melts the base metal, forming a crater into which the molten base metal and filler metal flow. As welding proceeds, the molten metal solidifies and a layer of slag forms on top of the weld. See Figure 11-1. The following factors allow for a quality weld with the proper penetration: electrode selection, arc length, current, travel speed, and electrode angle.

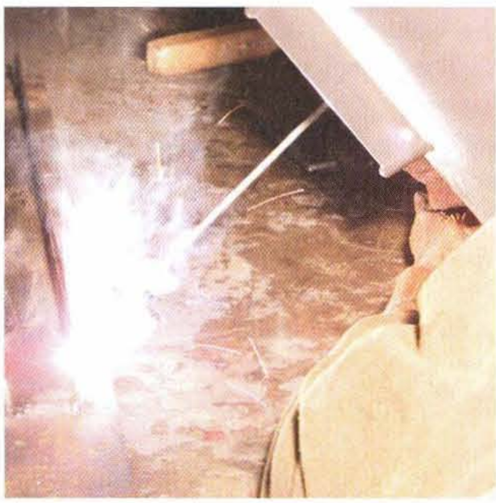


Figure 11-1. *Heat from the arc melts the base metal, forming a crater into which molten base metal and filler metal can flow to create a quality bead.*

The condition of electrode holders must be considered when setting arc welding variables. Electrode holders are exposed to extremely high heat on a regular basis, which causes them to deteriorate rapidly. Electrode holders should be checked regularly to ensure that they have not worn out and that current flows freely to the electrode.

Electrode Selection

Electrode selection must take into account the position of the weld, the properties of the base metal, the diameter of the electrode, the type of joint, and the current. Different electrodes are manufactured to meet various welding requirements.

Use the proper electrode for each welding operation.

Arc Length

If the arc length is too long, the metal melts off the electrode in large globules that wobble as the arc wavers. These large globules produce a wide, spattered, and irregular bead with insufficient fusion between the base metal and the deposited metal. An arc length that is

The arc length should be approximately the diameter of the electrode.

too short fails to generate enough heat to melt the base metal properly, producing high, uneven beads with irregular ripples. Depositing welds using too short an arc length also increases the possibility of the electrode sticking to the workpiece.

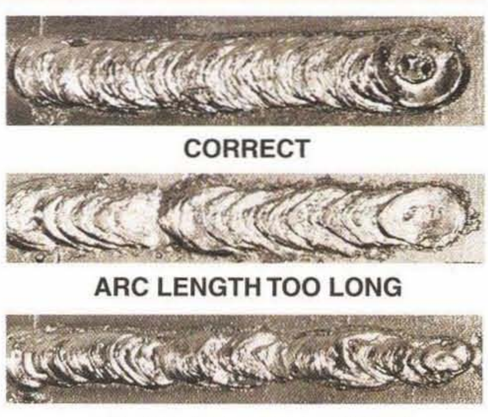
The arc length required depends on the size of electrode used and the welding task. Small-diameter electrodes require a shorter arc length than large-diameter electrodes. For better control of the weld pool, the arc length should typically be approximately the diameter of the electrode. For example, an electrode 1/8″ in diameter should have an arc length of about 1/8″. A shorter arc length is typically used for horizontal, vertical, and overhead welding because it gives better control of the weld pool.

Maintain a travel speed that is just fast enough to produce evenly spaced ripples.

The proper arc length also prevents impurities from entering a weld. A correct weld bead has the proper height and width and uniformly spaced ripples. A long arc length allows the atmosphere to flow into the weld area, permitting impurities of nitrides and oxides to form. Additionally, when the arc length is too long, heat from the arc stream is dissipated too rapidly, causing considerable metal spatter. See Figure 11-2. If the arc length is too short, the bead will have a narrow width and excessive height.

Figure 11-2. *Correct arc length is necessary for proper bead formation.*

Arc Length Effects
Figure 11-2



Use the correct current for a particular electrode.

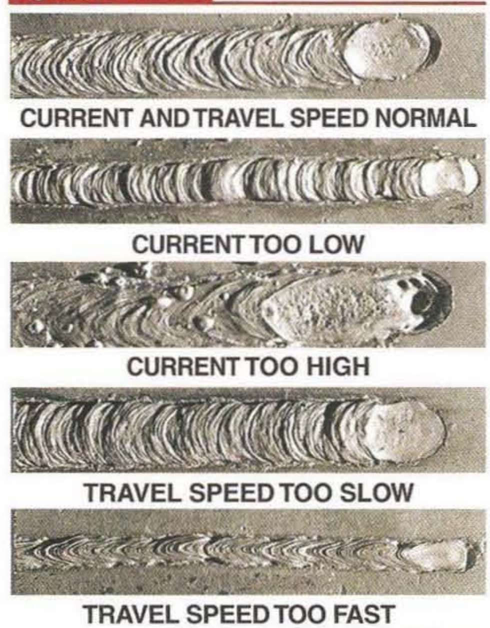
Current Selection

For the desired weld characteristics, the correct current (AC, DCEP, DCEN) for a particular electrode must be used. If the current is too high, the electrode melts too fast and the weld pool is large, irregular, and hard to control. Excessive spatter may also occur. When the welding current is too low, there is not enough heat to melt the base metal and the weld pool will be too small. The result is poor fusion, beads that pile up on the base metal and are irregular in shape, and the electrode can stick to the metal. Too low a current setting also causes the arc to continually break.

Travel Speed

If the travel speed is too fast, the weld pool does not last long enough and impurities are locked in the weld. The resulting bead is narrow, with pointed ripples. If the travel speed is too slow, the metal piles up excessively on the base metal and the bead is high and wide, with straight ripples. The correct travel speed produces a smooth weld bead with evenly spaced ripples. See Figure 11-3.

Bead Characteristics
Figure 11-3



The Lincoln Electric Company

Figure 11-3. *Proper bead formation is dependent on many variables, which must be controlled to prevent a poor-quality bead.*

Electrode Angle

The electrode angle affects the weld bead shape, particularly in fillet and deep groove welds. The electrode angle is determined by the travel angle and the work angle. *Travel angle* is an angle less than 90° between the electrode axis and a line perpendicular to the weld axis and in a plane determined by the electrode axis and the weld axis. The travel angle is along the weld axis and varies from 5° to 30° from the vertical, depending on welder preference and conditions. *Work angle* is an angle less than 90° in a line perpendicular to the workpiece and in a plane determined by the electrode axis and the weld axis. For example, the work angle normally is 90° when making a groove weld in flat position.

Ordinarily, a slight angle of the electrode in either direction from the work angle does not affect weld appearance or quality. However, when undercuts occur in the vertical plate of a fillet weld, the angle of the arc should be lowered and the arc directed more toward the vertical plate. Work angle is especially important in multiple-pass fillet welds. See Figure 11-4.

The depth of penetration should be one-third to one-half the total thickness of the weld bead.

CRATER FORMATION

As the arc comes in contact with the base metal, a crater is formed. A *crater* is a depression (pool or pocket) in the molten base metal made by the arc. The size and depth of a crater determine the amount of penetration. In general, the depth of penetration should be one-third to one-half the total thickness of the bead, depending on the size of the electrode. See Figure 11-5.

To obtain a sound weld, the metal deposited from the electrode must fuse completely with the base metal. Fusion results only when the base metal has been heated to a molten state and the

Be sure the molten metal from the electrode fuses completely with the base metal.

Electrode Angles
Figure 11-4

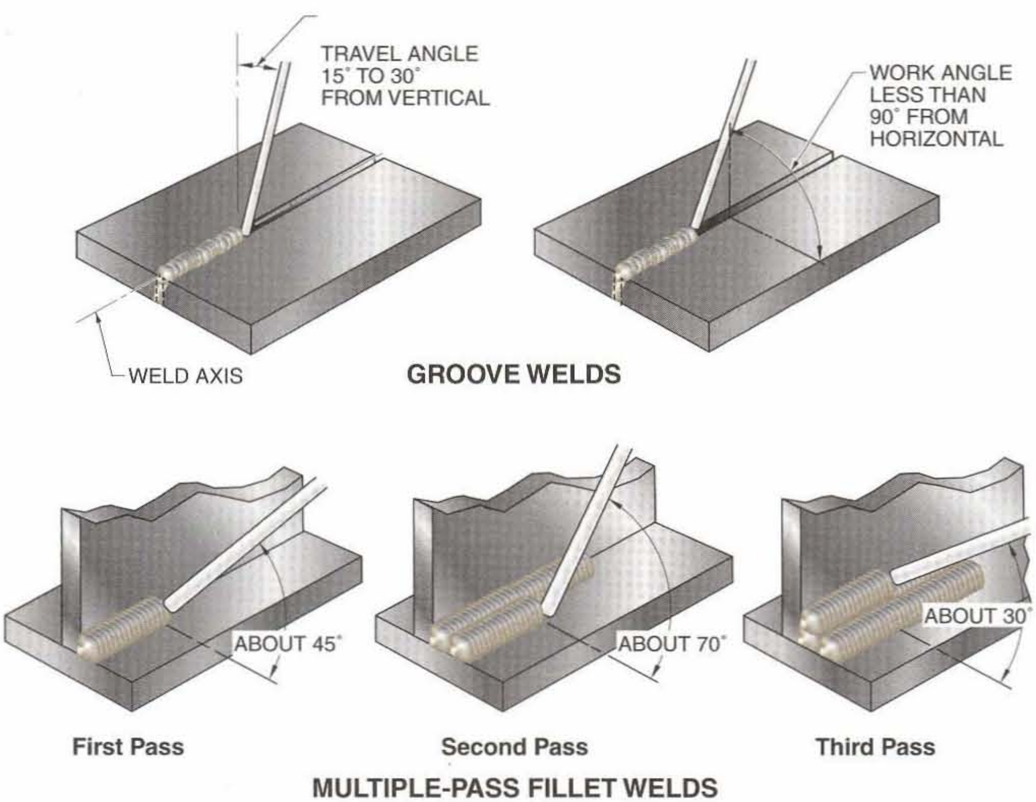


Figure 11-4. *The correct electrode angle is required to make a proper weld.*

molten metal from the electrode readily flows into it. If the arc length is too short, there is insufficient heat to form the correct size crater. When the arc length is too long, the heat is not centralized or intense enough to form the desired crater.

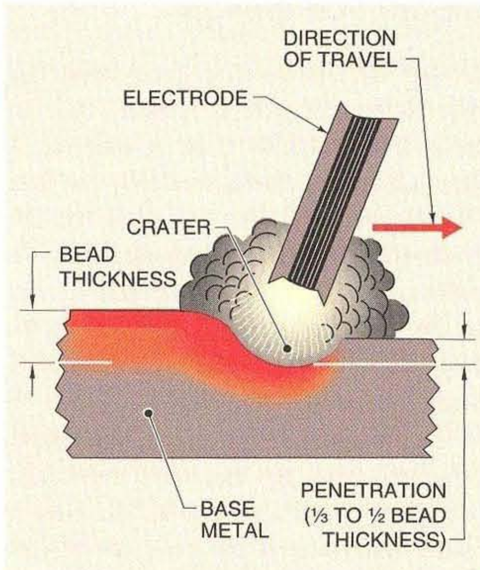


Figure 11-5. *The depth of the crater indicates the amount of penetration in the weld.*

Restart the electrode ½″ from the front edge of the previously made crater, move the arc back through the crater to remelt the weld pool, and continue welding.

Controlling Craters

An improperly filled crater does not produce the required weld strength and may cause a weld to fail when a load is applied. Occasionally, the crater gets too hot and the molten metal has a tendency to run. When this happens, the electrode should be lifted slightly and quickly shifted to the side or ahead of the crater. Such a movement reduces the heat, allows the crater to solidify, and stops the deposit of metal from the electrode. The electrode is then quickly returned to the crater and the arc shortened.

Another method used by welders to control the temperature of the molten weld pool is a whipping motion of the electrode. The whipping-motion technique is used with E-6010 and E-6011 electrodes and is especially helpful when welding pieces that have poor fit-up (large openings between workpieces). It is also used in overhead and vertical welding to better control the weld pool.

In a whipping motion, the electrode is struck and held momentarily. It is then moved forward about ¼″ or ⅜″. Just as the weld pool begins to freeze, the electrode is moved back into the center of the weld pool and the sequence is repeated. The electrode is moved by pivoting the wrist and not moving the arm while making the pass.

Remelting Craters. When starting an electrode, there is a tendency for a large globule of metal to fall on the surface of the plate, resulting in little or no penetration. This is particularly a problem when restarting an electrode at the crater from a previously deposited weld. To fill the existing crater and obtain proper fusion, strike the arc approximately ½″ in front of the crater and move the arc back through the crater. See Figure 11-6. At the back edge of the crater, dip the electrode into the weld pool and continue welding, completely filling the crater and ensuring proper penetration of the weld.

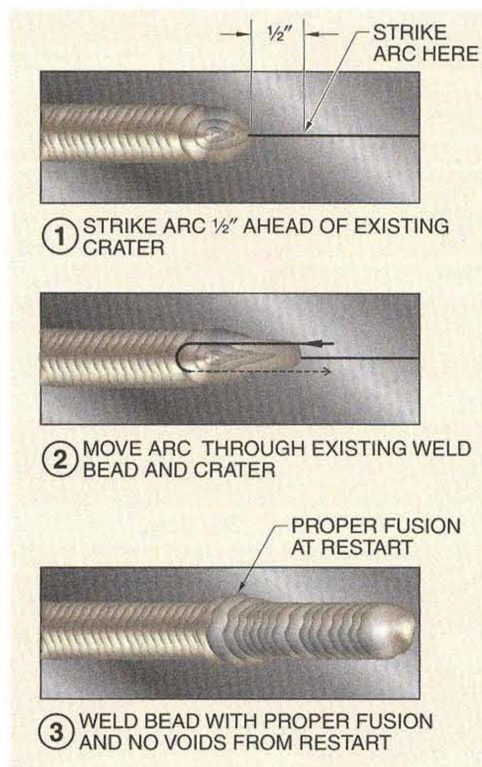


Figure 11-6. *To continue a bead, strike the arc ½″ from the front edge of the previously deposited weld bead and move the electrode back over the crater. At the back edge of the crater, dip the electrode to remelt and continue with welding, properly filling the crater.*

Completely remove flux from the crater before restarting the arc or discontinuities may result with possible porosity or slag inclusions.

Undercutting and Overlapping. *Undercutting* is creating a groove in the base metal that is not completely filled by weld metal during the welding process. Undercutting is the result of welding with excessive current. Excessive current leaves a groove in the base metal along both sides of the bead, which greatly reduces the strength of a weld. See Figure 11-7. Undercutting may also occur when there is insufficient deposition of metal on a vertical plate. Undercutting can be corrected by slightly changing the electrode angle.

Undercutting
Figure 11-7

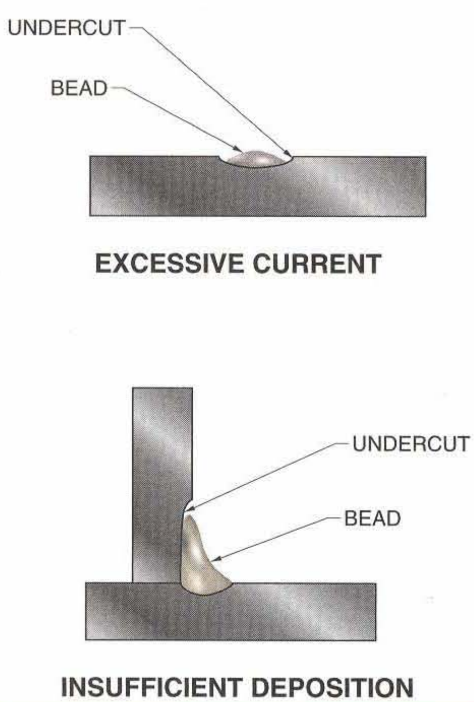


Figure 11-7. *Undercutting is caused by excessive current and/or insufficient metal deposition.*

Overlapping is extending the weld metal beyond the weld toes. Overlapping occurs when the current is set too low. In this instance, the molten metal is deposited without actually fusing into the base metal, creating a poor quality weld. See Figure 11-8.

Overlapping
Figure 11-8

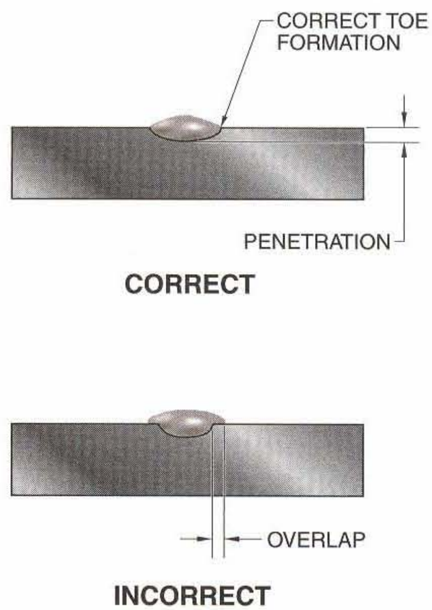


Figure 11-8. *Welding with too low current results in poor penetration and causes overlapping.*

Arc Blow

Arc blow is a deflection of the welding arc by magnetic forces that occur due to electron flow. When DC current is used, it produces a magnetic field around the electrode. The uneven movement of the current causes the arc to deflect from the weld area. Extreme heat can also cause arc blow.

Arc blow is a common problem when welding with DC current. Current in a DC welding machine flows in one direction, which produces a strong magnetism in the metal being welded. This magnetism causes the arc to deflect from the weld area. Arc blow also breaks the continuity of the deposited metal, making it necessary to refill the crater. The process of refilling the crater slows down the welding and often leaves weak spots in the weld. Using the proper current setting corrects or prevents arc blow.

Arc blow typically occurs in steel and metals that contain iron, but may be encountered in other metals as well. It is also more common in corners and near the ends of the workpiece when the work lead is connected on only one side of the metal.

Avoid undercutting and overlapping of the weld joint by using the correct current and electrode angle.

Prevent arc blow during welding by using AC rather than DC on jobs where arc blow may be a problem.

Arc blow usually occurs forward or backward along the joint but may occasionally occur to the sides. See Figure 11-9.

Arc blow may result when welding toward the workpiece connection near the end of a joint or in a corner. Arc blow can also occur anywhere near an end or a corner, and can continue to the end of the joint. As the weld pool nears the end of a workpiece, it becomes more packed and arc blow increases.

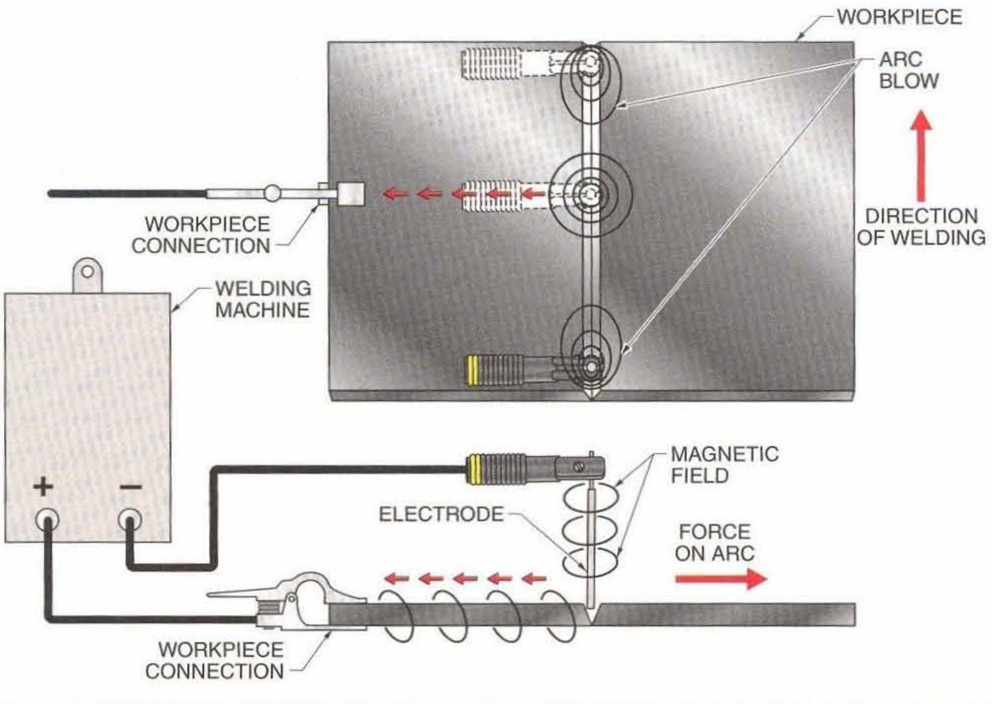
Arc blow results in incomplete fusion and excessive spatter. If arc blow is severe enough, a satisfactory weld cannot be made. The easiest method to reduce or prevent arc blow is to use AC rather than DC on jobs where arc blow may be a problem. Arc blow can also be prevented by clamping the workpiece connection to the end of the workpiece, rather than one side. Additional measures that may be taken to prevent arc blow include the following:

- welding away from the workpiece connection
- reducing the welding current
- using the backstep welding technique
- using the shortest possible arc to overcome the magnetic field

All electrical conductors create a magnetic field when current is flowing, which can interfere with welding by creating arc blow. AC current is not affected by arc blow because the current is constantly changing direction. The reversals in current in an AC circuit counteract the effects of the magnetic force on the base metal.

Figure 11-9. *Arc blow is caused by the magnetism produced by a DC welding machine that causes the arc to deflect from the weld area.*

Arc Blow
Figure 11-9



Cleaning Welds

The layer of slag that covers a deposited bead must be removed after welding. If a multiple-pass weld is required, the slag must be removed between each pass. Slag allowed to enter the weld metal will weaken the weld. Additionally, finishing procedures, such as painting, should not be performed until all slag is removed. See Figure 11-10. To remove slag from a weld:

1. Strike the weld area with a chipping hammer. Hammer the bead so the chipping is directed away from the eyes, the face, and the body.

   Do not pound the bead too hard as the structure of the weld may be damaged. After the slag is loosened, drag the point end of the chipping hammer along the weld where it joins the workpiece to loosen any remaining particles of slag.
2. After the chipping hammer, use a stiff wire brush to remove residual slag particles.

Cleaning Welds
Figure 11-10

(1) STRIKE WELD AREA WITH CHIPPING HAMMER

(2) REMOVE REMAINING SLAG WITH WIRE BRUSH

Figure 11-10. *Strike the weld with a chipping hammer, and then rub with a wire brush to remove slag.*

⚠ WARNING

Always wear safety glasses and required personal protective equipment when chipping slag.

When cleaning slag from a weld, direct chipping away from the body, the eyes, and the face.

POINTS TO REMEMBER

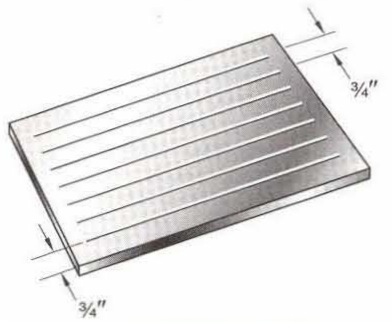
1. Use the proper electrode for each welding operation.
2. The arc length should be approximately the diameter of the electrode.
3. Use the correct current for a particular electrode.
4. Maintain a travel speed that is just fast enough to produce evenly spaced ripples.
5. The depth of penetration should be one-third to one-half the total thickness of the weld bead.
6. Be sure the molten metal from the electrode fuses completely with the base metal.
7. Restart the electrode ½″ from the front edge of the previously made crater, move the arc back through the crater to remelt the weld pool, and continue welding.
8. Avoid undercutting and overlapping of the weld joint by using the correct current and electrode angle.
9. Prevent arc blow during welding by using AC rather than DC on jobs where arc blow may be a problem.
10. When cleaning slag from a weld, direct chipping away from the body, the eyes, and the face.

Exercises

Depositing a Continuous Bead

exercise 1

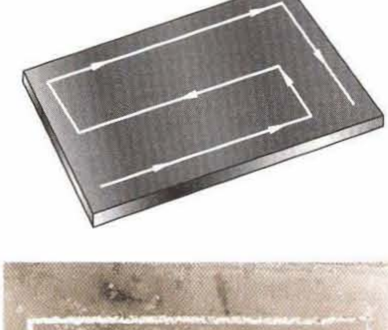
1. Obtain a piece of 1/4″ mild steel, 4″ wide by 6″ long.
2. Position the workpiece in flat position.
3. With a soapstone, draw a series of lines approximately 3/4″ apart and the length of the workpiece.
4. Use 1/8″; E-6010, E-6011, E-6012, or E-6013 electrode. Deposit continuous beads along the lines. Start from the left edge and work to the right.
5. After each line has been filled, remove the slag and examine the weld beads.

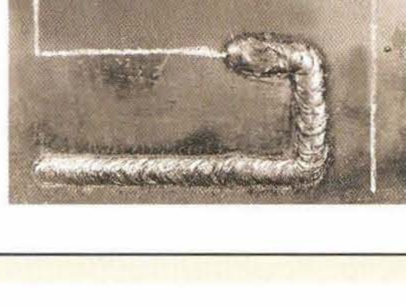


Moving the Electrode in Several Directions

exercise 2

1. Obtain a piece of 1/4″ mild steel.
2. Position the workpiece in flat position.
3. With a soapstone, draw a series of lines to form rectangles on the workpiece.
4. Deposit a continuous bead, moving the electrode from left to right, bottom to top, right to left, and top to bottom.
5. Maintain correct arc length, travel angle, and travel speed to control bead formation.

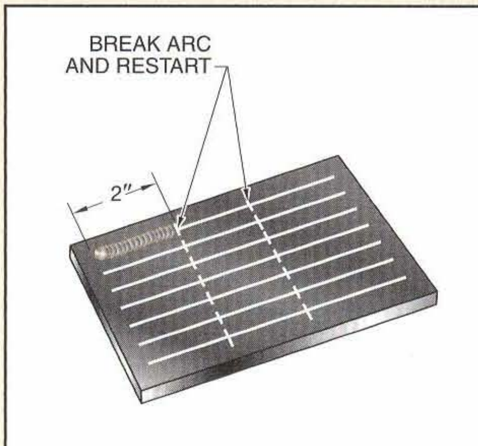




Restarting the Arc

exercise 3

1. Obtain a piece of ¼″ mild steel.
2. Position the workpiece in flat position.
3. With a soapstone, draw a series of straight lines, divided into 2″ sections.
4. Deposit a bead over the first 2″ section, then break the arc.
5. Deposit a bead for another 2″; then repeat the practice of breaking the arc and refilling the crater.



QUESTIONS FOR STUDY AND DISCUSSION

1. What factors allow for a quality weld with the proper penetration?
2. What factors must be considered when selecting an electrode?
3. How is a crater affected when the arc length is too long? What happens when the arc length is too short?
4. When the arc length is too long, what happens to the metal as it melts from the electrode?
5. How is it possible to identify a weld that has been made with too long an arc length?
6. What is likely to happen to the electrode when the arc length is too short?
7. What are some characteristics of a weld made with too short an arc length?
8. What are some factors that must be considered when determining arc length?
9. In what way does the amount of current affect a weld?
10. What determines the travel speed at which an electrode should be moved?
11. What is a crater?
12. What should be the depth of penetration?
13. What should be done when the crater gets too hot and the metal has a tendency to run over the surface?
14. How should an electrode be restarted to fill a crater left from a previously deposited weld?
15. What causes undercutting? How can undercutting be prevented?
16. List six ways to prevent arc blow.
17. How should slag from a weld be removed from a workpiece?

12 SMAW - Flat Position

The easiest position in which to weld is in flat position. When welding in flat position, the welding speed can be increased, molten metal has less tendency to run, better penetration of the base metal is possible, and the welding operation is less tiring for the welder. If possible, structures should be positioned so that they can be welded in the easier and more efficient flat position.

WELD PASSES

Some welds require more than one pass. In a multiple-pass weld, the first pass is the root pass. Additionally, intermediate weld pass(es) and a cover pass are used for multiple-pass welding. Some welding operations require the workpieces to be tack welded. A tack weld is used to hold the workpieces in proper alignment until the final welds are made. Tack welds are spaced along the joint and must be consumed into the joint during welding. Once the joint is tacked, the necessary weld passes are made. See Figure 12-1.

Root Pass

A *root pass* is the initial weld pass that provides complete penetration through the thickness of the joint member. The root pass (bead) is the first weld pass made and is deposited in the bottom of the root. The root bead is made by moving a small-diameter electrode straight down into the groove without any weaving motion. The purpose of the root bead is to join the two workpieces and fill the root opening.

The root bead serves as the base for subsequent passes, and it must produce complete penetration. Complete penetration is ensured if the root bead penetrates the bottom surface of the groove and consumes all tack welds previously made. Penetration of the root bead should not exceed fabrication code criteria or, if not given, 1/16″ beyond the bottom surface of the joint. Thoroughly remove slag from the root bead before laying the next pass.

Tack welds are used to keep workpieces in position. They must be consumed into the joint during welding.

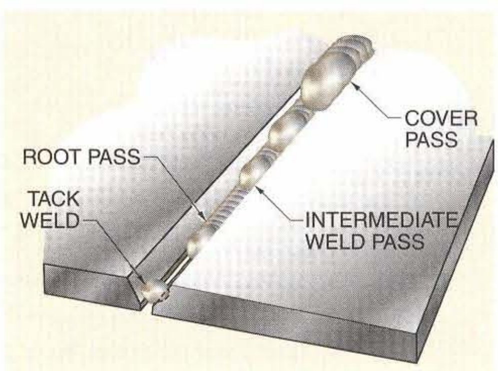


Figure 12-1. *Weld passes used for multiple-pass welding are the root pass, intermediate weld pass(es), and the cover pass.*

Intermediate Weld Pass

An *intermediate weld pass* is a single progression of welding subsequent to the root pass and before the cover pass. Intermediate weld pass replaces terminology for both the hot pass and the filler pass. The first intermediate weld pass may be used after the root pass to correct undercut or overlap. The first intermediate weld pass uses

When depositing a root bead, advance a small-diameter electrode along the groove with no weaving motion.

An intermediate weld pass may be used to remove slag inclusions or other defects from the root bead.

a high current setting and a fast travel speed to blow out any remaining slag or inclusions and to create a quality weld surface for additional passes. The first intermediate weld pass deposits a small amount of filler metal and, when completed, should form a concave bead. The first intermediate weld pass must be thoroughly cleaned before depositing additional weld passes.

Additional intermediate weld passes may be needed to fill the groove, depending on the thickness of the metal. When depositing intermediate weld passes, a slight weaving motion is generally used to ensure proper fusion with the previously deposited beads and the sides of the groove joint. When multiple passes are used, the beads should slightly overlap to ensure a smooth surface. Each pass must be thoroughly cleaned of slag before additional passes are made. Intermediate weld passes must completely bond to the previous passes, but should not penetrate too deeply to prevent remelting previous passes and weakening the weld.

Use a slight weaving motion when depositing intermediate weld passes.

Cover Pass

A *cover pass* is the final weld pass deposited. The cover pass provides additional reinforcement to a multiple pass weld and provides a good appearance. The cover pass should not extend beyond the fabrication code criteria or, if not given, more than $1/16''$ above the base metal surface. A weaving motion is used on the cover pass to obtain the necessary weld width when covering the filler passes.

JOINTS WELDED IN FLAT POSITION

When welding a joint with base metals of different thicknesses, keep the heat concentrated on the thicker metal.

Flat position is the most efficient position for welding any joint. However, even in flat position, some joints require special techniques. For example, when a joint consists of two pieces of metal having different thicknesses, the work angle of the electrode should be adjusted so that the heat is concentrated on the thicker metal. See Figure 12-2. Joints commonly welded in flat position include lap, T, butt, and corner joints.

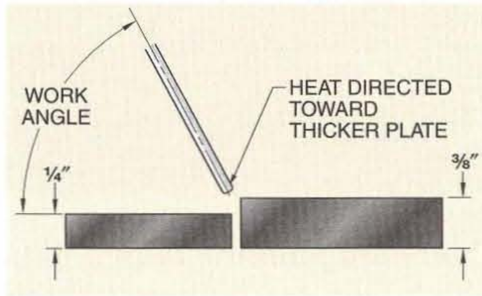


Figure 12-2. *When welding base metals of different thicknesses, direct more heat to the thicker metal.*

Lap Joints

The lap joint is one of the most frequently used joints in flat position welding. It is a relatively simple joint, since no beveling or machining is necessary. Surfaces to be welded must be clean and evenly aligned. A lap joint consists of lapping one workpiece over another and joining. The amount the workpieces should overlap depends on the thickness of the metal and the strength required. A fillet weld is used to join the two workpieces. Usually the thicker the metal, the greater the amount of overlap needed. When the structure is subjected to heavy bending stresses, it is best to deposit welds on both sides of the joint. See Figure 12-3.

Lap Joints
Figure 12-3

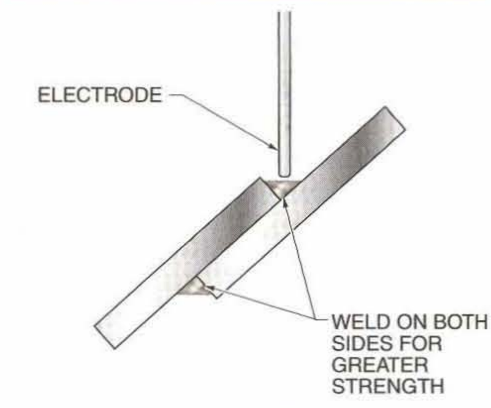


Figure 12-3. *A lap joint typically does not require edge preparation before welding. Welding both sides of the lap joint provides greater strength.*

A lap joint is adaptable for a variety of new construction work as well as for many types of repairs. For example, a lap joint can be used when joining a series of metal plates together or when reinforcing another structural member. Since a lap joint stiffens the structure where the metals are lapped, it is used a great deal in ship building.

When an exceptionally strong lap joint is required, especially on workpieces $\frac{3}{8}$″ thick or more, a multiple-pass fillet weld is recommended. This weld has two or more layers of beads along the seam, with each bead lapping over the other.

T-Joints
Figure 12-4

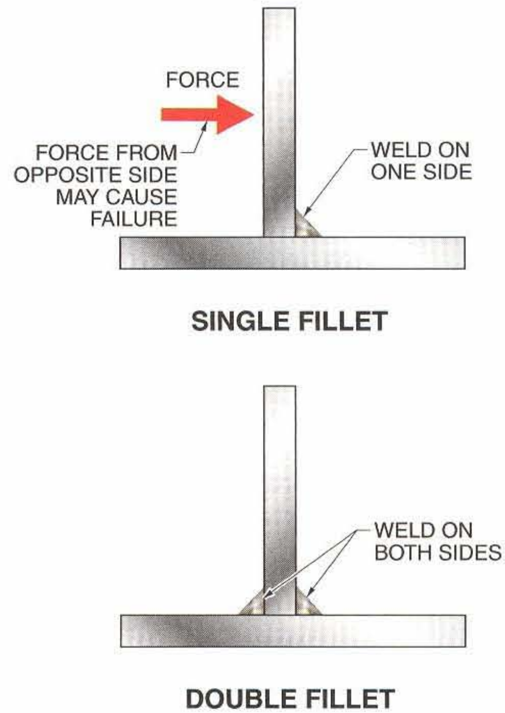


Figure 12-4. *The strength of a T-joint depends on proper fit-up, the direction from which a force is applied, and whether a single or double fillet joint is used.*

When welding a lap or T-joint, weld the joint on both sides if the structure is to be subjected to heavy stresses.

T-Joints

A T-joint is frequently used in fabricating straight and rolled shapes. The strength of the joint depends on a close fit-up of the joint edges. A T-joint should not be used on structures subjected to heavy stresses from the opposite side of the welded joint. This weakness can be partially overcome by using a double fillet weld. See Figure 12-4. When welding thick metal, or when extra strength is required, a larger fillet is necessary. Fillet welds can be made larger by depositing several passes.

Butt Joints

A butt joint may be closed, open, or prepared, such as beveled. See Figure 12-5. On a closed butt joint, the edges of the two workpieces are in direct contact with each other. A closed butt joint is suitable for welding steel that generally does not exceed $\frac{3}{16}$″ thick. Thicker metal can be welded, but only if the welding machine has sufficient current capacity and if larger diameter electrodes are used. On thicker metal, multiple passes are required because it is difficult to achieve enough penetration to produce a strong weld with one pass.

The edges of an open butt joint are spaced slightly apart, usually $\frac{3}{32}$″ to $\frac{1}{8}$″, to allow for penetration of the filler metal and expansion of the base metal. Generally, a backing bar or block of scrap steel is placed under an open butt joint. See Figure 12-6. A backing bar prevents the bottom edges from burning through.

Butt Joints
Figure 12-5

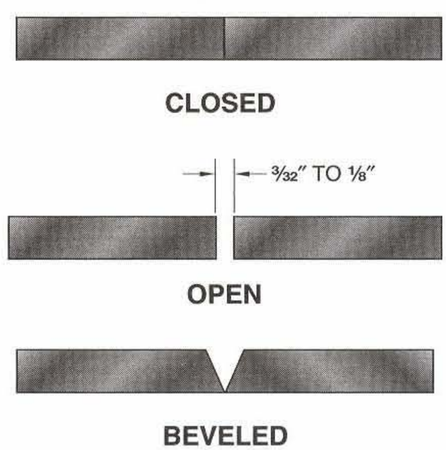
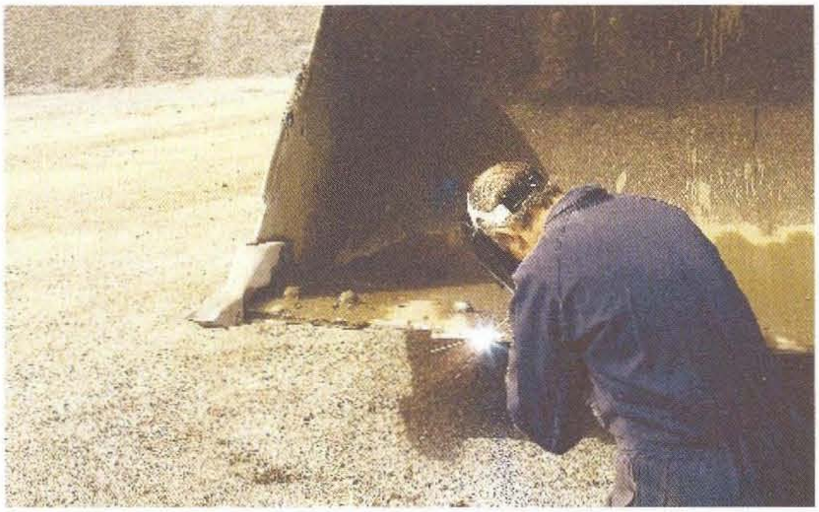


Figure 12-5. *A butt joint may be closed, open, or beveled.*

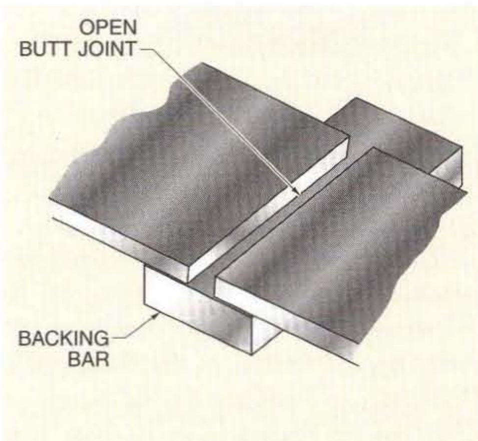
The edges of an open butt joint should be spaced about $\frac{3}{32}$″ to $\frac{1}{8}$″ apart for penetration and joint expansion.



Thermadyne Industries, Inc.

Construction equipment commonly uses surfacing welds with SMAW for building up worn parts and producing a hardened surface.

Figure 12-6. *A backing bar prevents the bottom edges from burning through an open butt joint.*



When welding a butt joint on metal more than 3⁄16″ thick, bevel the edges to obtain the proper penetration.

When the thickness of the metal exceeds 1⁄8″, the edges of a butt joint should be beveled. Beveling the edges ensures better penetration, requires less weld metal, and equalizes contraction forces. Beveling can be done by cutting the edges with a flame torch or by grinding on a grinder. The groove angle should not exceed 60° to limit the amount of contraction that usually results when the metal cools. The edges may be prepared in several ways, such as a single-V, single-V with root face, or double-V with root face. See Figure 12-7. The thickness of the workpieces determines the edge preparation required. For example, on metal 3⁄8″ thick or more, the edges are beveled on both sides.

When welding thin stock with a single pass, as in a closed or open butt joint, move the electrode along the joint without any weaving motion. Move the electrode slowly enough to allow the arc sufficient time to melt the metal. Using too slow a travel speed can cause the arc to burn through the metal.

When a multiple-pass weld is to be made in a beveled joint, move the electrode down in the groove so that it almost touches both sides of the joint while depositing the root bead. Move the electrode fast enough to keep the slag flowing back on the finished weld. If the electrode is not moved rapidly enough, slag may become trapped in the bottom of the weld, preventing proper fusion. After completing the root bead, proceed with the necessary intermediate weld passes. Complete the weld with a cover pass.

Butt Joint Edge Preparation
Figure 12-7

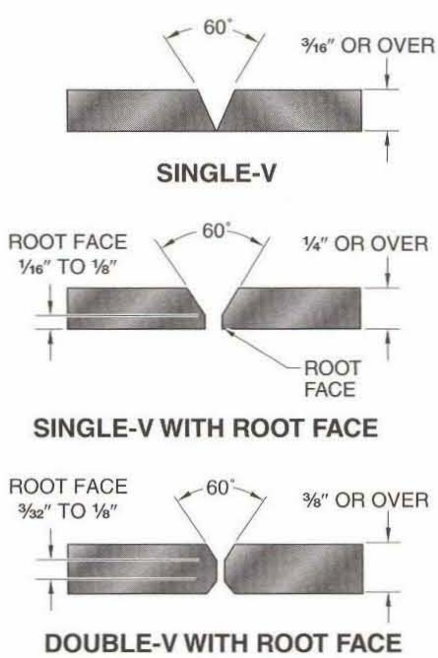


Figure 12-7. *The edges of a butt joint are prepared in different ways, depending on the thickness of the metal.*

A butt joint is often used when joined structural pieces must have a flat surface, such as in tanks, boilers, and a variety of machine parts. See Figure 12-8.

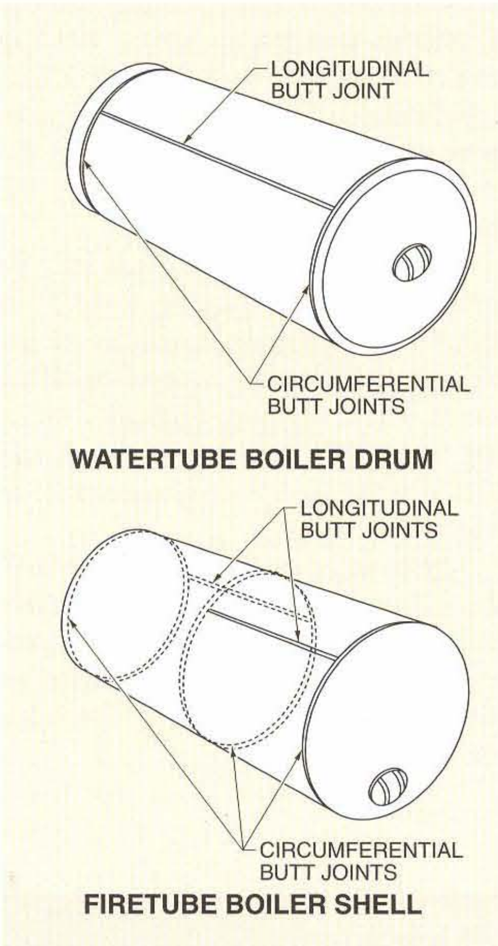


Figure 12-8. *Butt joints are often used for structures such as boilers.*

Corner Joints

An outside corner joint may be used when constructing rectangular objects such as tanks, metal furniture, and other machine sections where the outside corner must have a smooth radius. A single pass is usually sufficient for welding corner joints.

A worn part is ground down or machined to allow for two layers of surfacing to be deposited on the part. The first layer of deposited metal tends to become diluted and loses some of its alloying properties when mixed with the base metal. Additional layers of surfacing provide the required wear properties while maintaining the part thickness.

SURFACING

Surfacing is the application of a layer or layers of material to a surface to obtain desired properties or dimensions. Surfacing is commonly performed in flat position and is used to repair worn surfaces of shafts, wheels, and other machine parts. The worn base metal has a surfacing weld applied, which is then machined to specifications. A *surfacing weld* is a weld applied to a surface, as opposed to a joint, to obtain desired properties or dimensions. The operation consists of depositing several layers of welds, one on top of the other, to increase the dimensions of a part. See Figure 12-9.

Always remove slag completely after each pass. Slag particles allowed to remain weaken the weld.

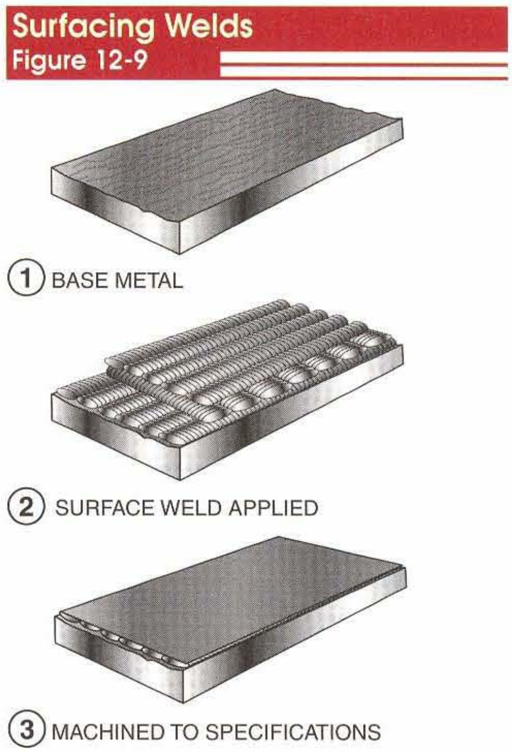
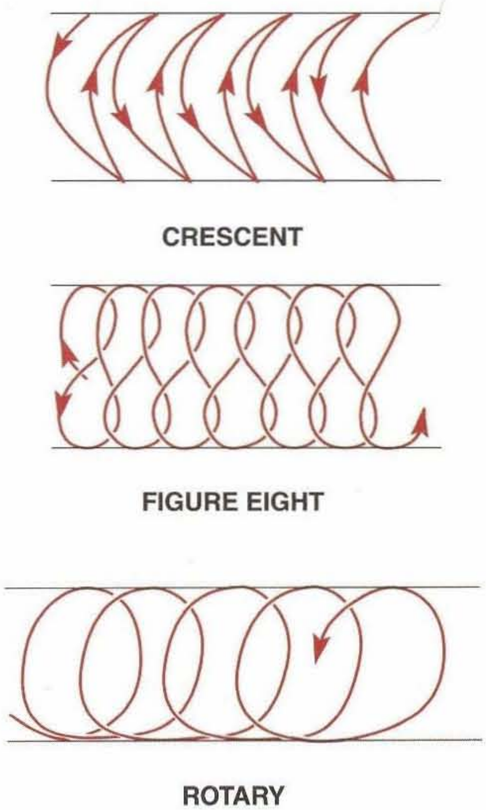


Figure 12-9. *Surfacing welds are used to increase the dimensions of parts.*

Surfacing is performed by depositing successive weld beads. Additional filler metal can be added by weaving. *Weaving* is a welding technique in which the energy source is moved transversely as it progresses along the weld joint. Weaving increases the bead width. Three weave patterns commonly used are the crescent, figure eight, and rotary motion, depending on the position and joint. See Figure 12-10. Weaving is also used to provide a smooth weld finish on multiple pass welds.

Figure 12-10. *Three common weave patterns, crescent, figure eight, and rotary, are used to increase the width and volume of the weld bead.*

Weave Patterns
Figure 12-10



Remedy welding problems quickly when performing SMAW in flat position to prevent weakness or failure of the weld.

SMAW FLAT POSITION PROBLEMS

When welding in flat position, gravity helps direct the flow of molten weld metal. Welding is normally best performed in flat position, but many welding tasks require other positions. Problems that occur during welding can result in joint weakness and/or failure. Common SMAW flat position problems can be remedied by analyzing the specific problem and determining the cause.

Some of the problems that may be encountered when using SMAW in flat position include instability of the arc, poor penetration, a loud crackling noise when welding, difficulty striking an arc, weakness of the weld, and arcing at the workpiece connection. See Figure 12-11.

Problems that occur during SMAW are often the result of improper settings on the welding machine. Adjusting the current, changing polarity, or correcting a poor ground should solve the problem.

SMAW WELDING PROBLEMS

Problem	Cause	Remedy
Unstable arc. Arc goes out, spatters over work	Arc too long	Shorten arc
Poor or no penetration. Arc goes out often	Not enough current for size of electrode. Wrong electrode	Increase current. Use proper electrode
Loud crackling from arc. Flux melts too rapidly. Wide bead, spatter in large drops	Too much current for electrode. May be moisture in electrode cover	Decrease current
Difficulty in striking arc. Poor penetration	Wrong polarity. Too little current	Change polarity. Or, increase current
Weak weld. Arc hard to start. Arc keeps breaking	Dirty work	Clean work. Remove slag from previous weld
Arcing at ground clamp	Poor ground	Properly ground work

Figure 12-11. *A welder should be alert to any signs of a problem during welding, such as instability of the arc or poor penetration, and remedy the situation quickly.*

POINTS TO REMEMBER

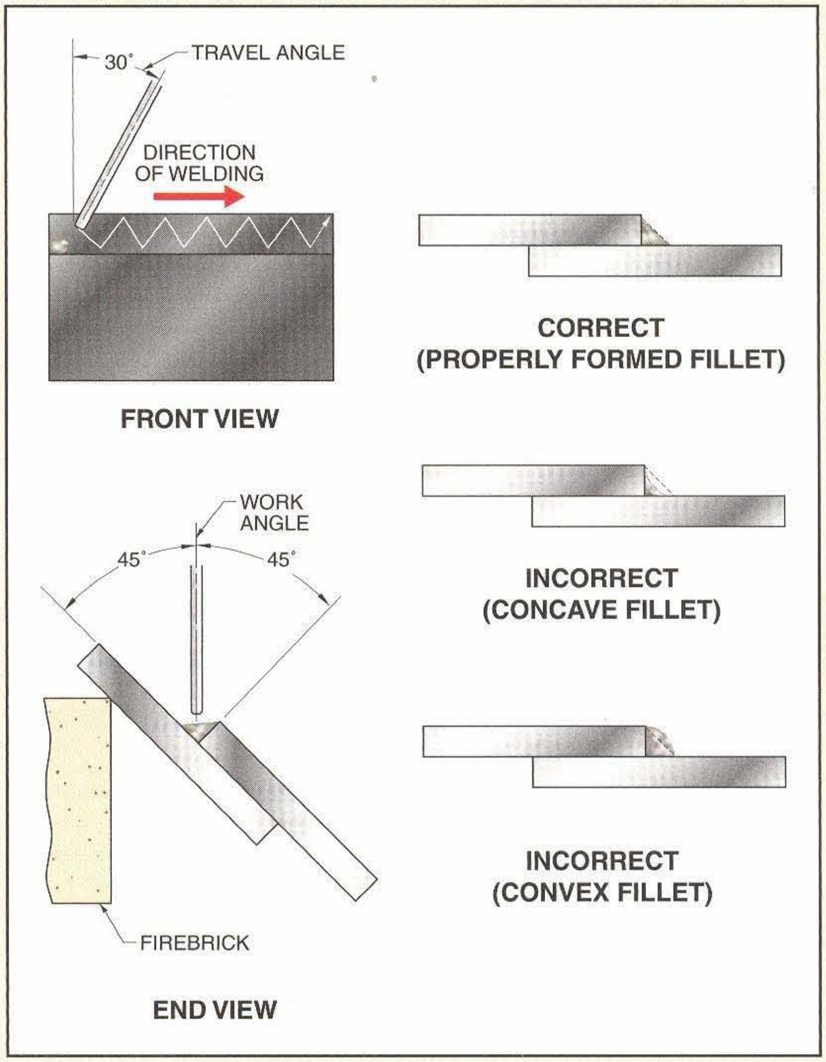
1. Tack welds are used to keep workpieces in position. They must be consumed into the joint during welding.
2. When depositing a root bead, advance a small-diameter electrode straight along the groove with no weaving motion.
3. An intermediate weld pass may be used to remove slag inclusions or other defects from the root bead.
4. Use a slight weaving motion when making intermediate weld pass(es).
5. When welding a joint with base metals of different thicknesses, keep the heat concentrated on the thicker metal.
6. When welding a lap or T-joint, weld the joint on both sides if the structure is to be subjected to heavy stresses.
7. The edges of an open butt joint should be spaced about 3⁄32″ to 1⁄8″ apart for penetration and joint expansion.
8. When welding a butt joint on metal more than 3⁄16″ thick, bevel the edges to obtain the proper penetration.
9. Always remove slag completely after each pass. Slag particles allowed to remain weaken the weld.
10. Remedy welding problems quickly when performing SMAW in flat position to prevent weakness or failure of the weld.

Exercises

Welding a Single-Pass Lap Joint in Flat Position

exercise 1

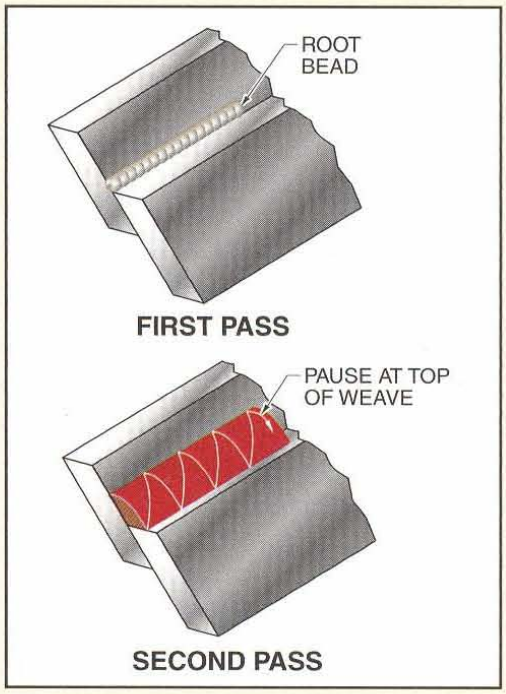
1. Obtain two pieces of 3/16″ or 1/4″ mild steel.
2. Form a lap joint and tack together.
3. Position the workpiece so the weld joint is in flat position.
4. Use a 1/8″ electrode and adjust the welding machine for the correct current.
5. Hold the electrode at a 45° angle and deposit a 1/4″ fillet weld along the joint.
6. Weave the electrode slightly, maintaining the arc for a slightly longer time on the bottom workpiece.
7. Make sure that fusion is complete at the joint root and prevent overlapping on the top workpiece. A weld made with a concave fillet is usually too weak because it lacks sufficient reinforcing metal. A weld with a convex bead has too much waste metal, which adds no strength to the weld.



Welding a Multiple-Pass Fillet Lap Joint in Flat Position

exercise 2

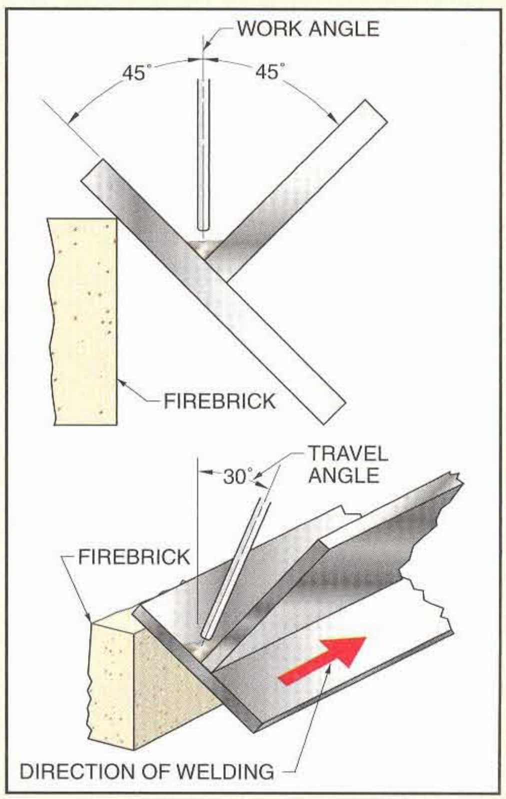
1. Obtain two pieces of ¼″ mild steel.
2. Form a lap joint and tack together.
3. Position the workpiece so the weld joint is in flat position.
4. Deposit the root bead by moving the electrode straight down the joint without weaving.
5. Clean the weld carefully with a chip hammer and wire brush and deposit the second pass over the root bead.
6. While welding the second pass, weave the electrode, pausing for an instant at the top of the weave to deposit extra metal on the surface of the upper plate.
7. Maintain a consistent bead width along the joint.



Welding a Single-Pass Fillet T-Joint in Flat Position

exercise 3

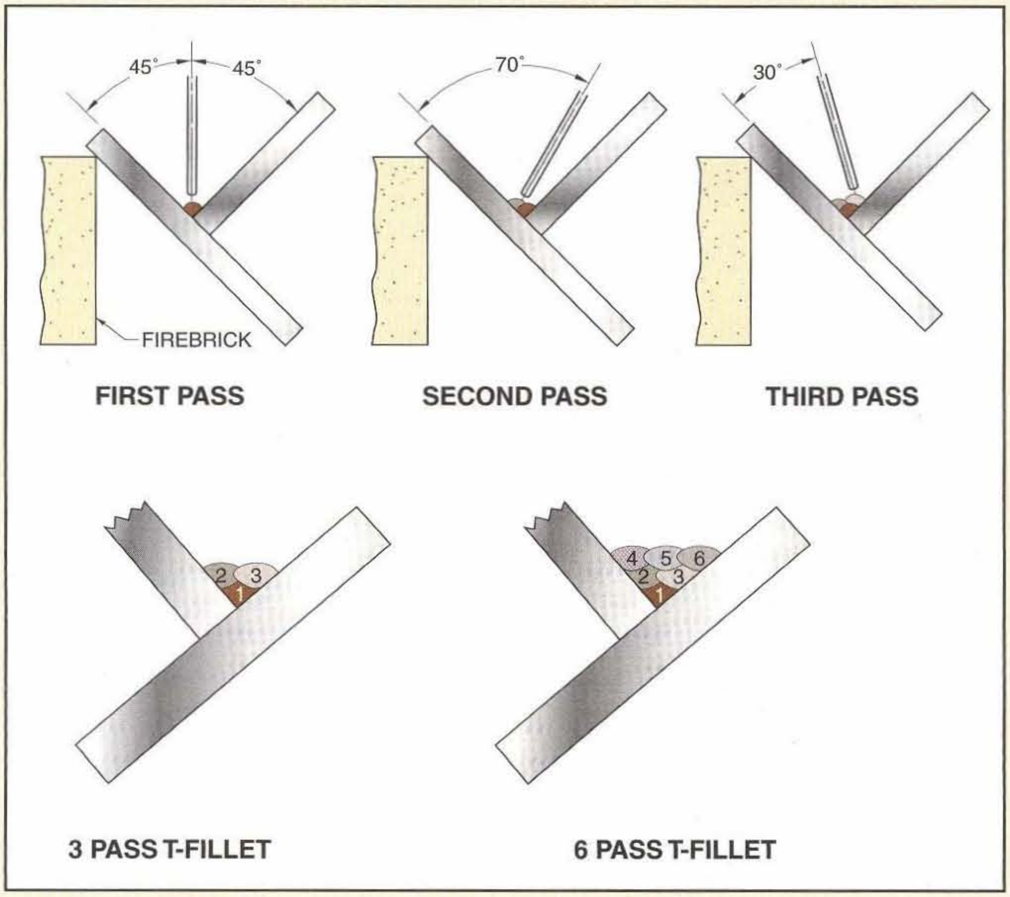
1. Obtain two pieces of ³⁄₁₆″ or ¼″ mild steel.
2. Form a T-joint with the pieces at a 90° angle and tack together.
3. Position the workpiece so the weld joint is in flat position.
4. Hold the electrode at a work angle of 45° and a travel angle of 30° and advance it in a straight line without any weaving motion. Deposit a ¼″ fillet weld.
5. Maintain travel speed to stay ahead of the weld pool. Concentrate the arc more on the bottom workpiece to prevent undercutting the top workpiece. Watch the crater closely to ensure that it forms a properly contoured bead.



Welding a Multiple-Pass Fillet T-Joint in Flat Position

exercise 4

1. Obtain two pieces of 3⁄16″ or 1⁄4″ mild steel.
2. Form a T-joint with the pieces at a 90° angle and tack together.
3. Position the workpiece so the weld joint is in flat position.
4. Deposit the root bead by moving the electrode straight down the joint without weaving. Remove slag completely.
5. Hold the electrode at a work angle of 70° and a travel angle of 30°. Deposit the first intermediate weld pass to partially cover the root bead. Remove slag completely.
6. Hold the electrode at a 30° work angle and a 30° travel angle. Deposit the second intermediate weld pass to cover the root bead and partially cover the second pass.
7. If more or less weld metal is required, make additional passes using different bead configurations.
8. Additional weld metal can be deposited on a multiple-pass fillet T-joint by weaving the electrode.

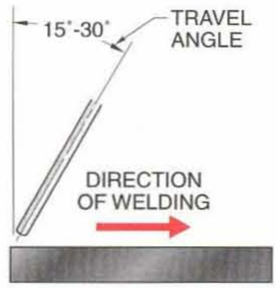


Welding a Butt Joint in Flat Position

exercise 5

1. Obtain two pieces of 3/16″ or 1/4″ mild steel.
2. Form a butt joint, with a root opening for expansion and tack together.
3. Position the workpiece so the weld joint is in flat position.
4. Hold the electrode at a work angle of 90° and a travel angle of 15° to 30°. Deposit a bead along the butt joint.
5. Let the workpiece cool and then repeat the procedure on the reverse side.

WORK ANGLE

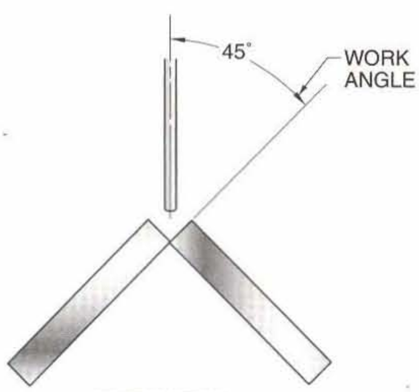


TRAVEL ANGLE

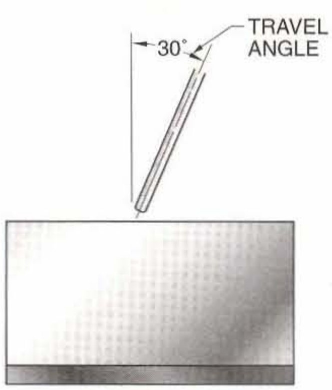
Welding an Outside Corner Joint in Flat Position

exercise 6

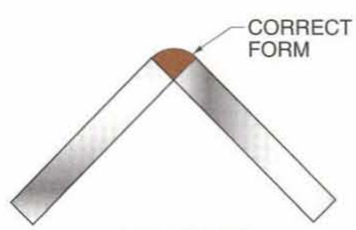
1. Obtain two pieces of 3/16″ or 1/4″ mild steel.
2. Form a corner joint with the pieces at a 90° angle and tack together.
3. Position the workpiece so the weld joint is in flat position.
4. Hold the electrode at a work angle of 45° and a travel angle of 30°. Deposit a bead along the outside of the joint.
5. For most corner joints, one bead is sufficient. Thick metals may require additional passes to fill the corner.



END VIEW



FRONT VIEW

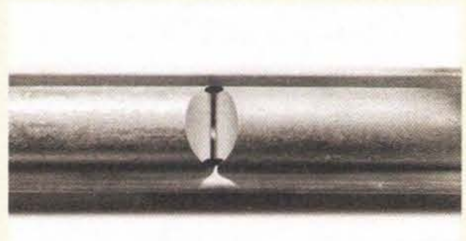


END VIEW (FINISHED WELD)

Welding Round Stock in Flat Position

exercise 7

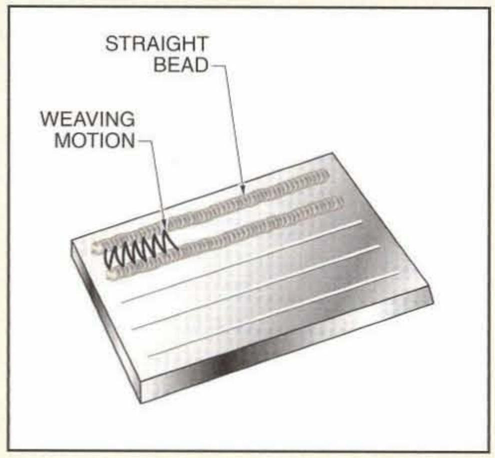
1. Obtain two pieces of round stock.
2. Form a butt joint with the beveled edges ground to the same groove angle.
3. Position the workpiece in a vise or section of angle iron so the weld joint is in flat position.
4. Deposit a small bead on one side. Then deposit a similar bead on the opposite side to prevent the shaft from warping.
5. Use a slight weaving motion on the last pass.



Weaving the Electrode

exercise 8

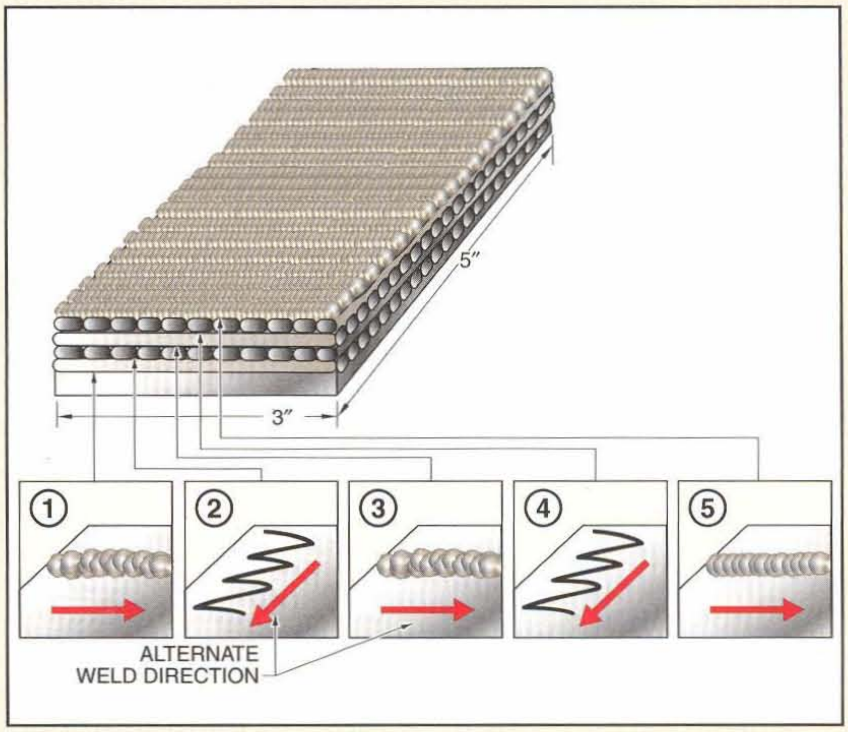
1. Obtain a piece of ¼″ mild steel, 4″ wide and 6″ long.
2. Draw a series of straight lines on the plate.
3. Position the workpiece in flat position.
4. Deposit continuous beads along the guide lines. Remove slag completely.
5. Practice weaving by depositing a weld back and forth between the first pair of continuous beads.
6. Use a different weave motion to fill each section. Ensure that the short beads are fused into the long, straight beads.
7. Continue to practice weaving on several plates until a satisfactory plate is completed.



Surfacing

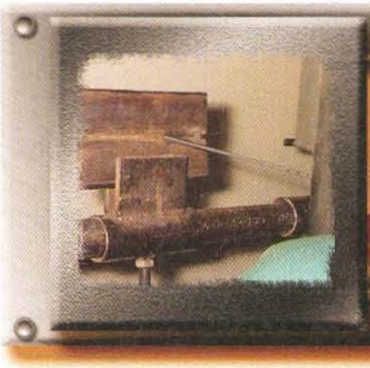
exercise 9

1. Obtain a piece of mild steel, ¼″ thick or more, 3″ wide, and 5″ long.
2. Position the workpiece in flat position.
3. Deposit a layer of straight beads to completely cover the workpiece surface. Remove slag completely.
4. Deposit a second layer of weaved beads about ½″ wide at right angles to the first layer. Remove slag completely.
5. Deposit a third layer of straight beads at right angles to the second layer. Remove slag completely.
6. Deposit a fourth and fifth layer, in the same manner—each layer at right angles to the previous layer, with slag thoroughly removed before the subsequent layer is added.



QUESTIONS FOR STUDY AND DISCUSSION

1. What is an advantage of welding in flat position rather than in other positions?
2. How are tack welds used in welding?
3. What is the function of a root pass?
4. What is a cover pass and why is it used?
5. What procedures are followed when welding plates of different thicknesses?
6. When making a lap weld, what determines how much the workpieces should overlap?
7. How can undercutting be avoided when welding a lap joint?
8. Why should a double fillet be used on a lap joint?
9. When should multiple passes be used on a lap joint?
10. When welding a T-joint, why should the arc be directed more toward the bottom workpiece?
11. What is the difference between an open and a closed butt joint?
12. When is a butt joint used in welding?
13. When should the edges of butt joints be beveled?
14. What determines the edge preparation required for welding a butt joint?
15. What are some common applications of outside corner welds?
16. How many passes should be made on an outside corner weld?
17. How should the edges of round stock be prepared for welding?
18. What work angle is used to weld a lap joint in flat position?
19. What work and travel angles are used when welding a butt joint in flat position?
20. What welding technique is recommended when making a root bead?
21. What work angles are used to weld a multiple-pass fillet T-joint weld?
22. What is the purpose of surfacing?
23. What is meant by weaving?
24. When is a weaving motion used?



SMAW – Horizontal Position 13

Shielded Metal Arc Welding (SMAW)

On many jobs, welding cannot be performed in flat position. Occasionally, the welding operation must be done while the work is in horizontal position. Welds performed in horizontal position must have a uniform, consistent bead. A fill-freeze or fast-freeze electrode should be used.

HORIZONTAL POSITION WELDING

A weld is in horizontal position when the workpiece is in a vertical position and the weld joint is approximately horizontal. See Figure 13-1. The weld bead must support the weld pool during welding to ensure sufficient buildup of the weld.

Figure 13-1. *In horizontal welding, the weld joint is in horizontal position.*

To weld in horizontal position, a short arc length should be used, with a slight reduction in current from that used for welding in flat position. The short arc length minimizes the tendency of the weld pool to sag and cause overlapping. An overlap occurs when the weld pool runs down to the lower side of the bead and solidifies on the surface without actually penetrating the base metal. A sagging weld pool usually leaves an undercut on the top side of the weld seam and an improperly shaped bead. See Figure 13-2. Overlaps and undercuts can weaken a weld.

Do not allow the molten weld pool to sag and cause overlaps and undercuts.

Horizontal Bead Formation
Figure 13-2

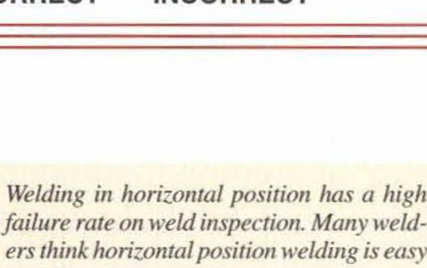


Figure 13-2. *Using a short arc length minimizes the tendency of the weld pool to sag and cause overlapping. Sagging weld pools usually leave an undercut area on the top side of the seam.*

Welding in horizontal position has a high failure rate on weld inspection. Many welders think horizontal position welding is easy and they don't pay close enough attention to the placement of the weld.

When welding in horizontal position, use a lower welding current and shorter arc length than when welding in flat position .

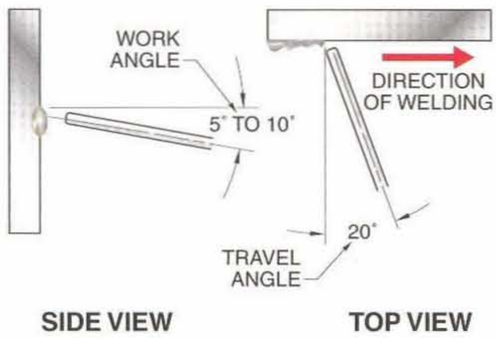
When welding in horizontal position, hold the electrode at a work angle of 5° to 10° and a travel angle of 20°.

Welding Procedure

When welding a butt joint in horizontal position, hold the electrode at a work angle of 5° to 10° and a travel angle of 20°. See Figure 13-3.

Figure 13-3. *When welding in horizontal position, hold the electrode at a work angle of 5° to 10° and a travel angle of 20°.*

Electrode Position
Figure 13-3



Use a slight weaving motion when welding in horizontal position.

When depositing the bead, use a narrow weaving motion. Weaving the electrode distributes heat more evenly, further reducing any tendency for the weld pool to sag. See Figure 13-4. Keep the arc length as short as possible. If the force of the arc has a tendency to undercut the workpiece at the top of the bead, slightly tilt the electrode upward to increase the upward angle.

A fill-freeze or fast-freeze electrode should be used for horizontal welding. As the electrode is moved in and out of the crater, pause slightly each time it is returned to the crater. This keeps the crater small and the bead is less likely to sag.

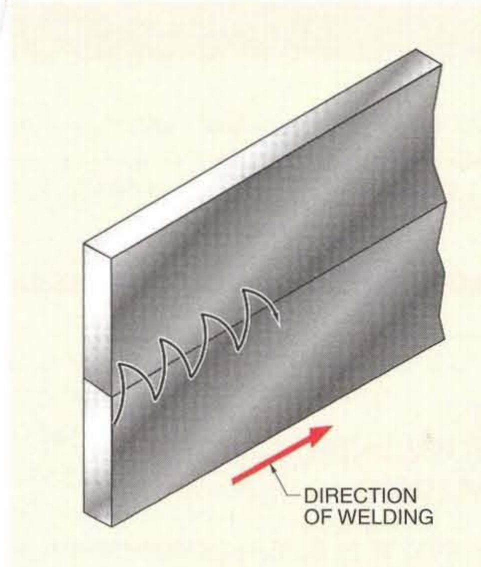


Figure 13-4. *Use a slight weaving motion when welding in horizontal position to distribute heat more evenly.*

In horizontal position welding, the position of the electrode is changed for each pass. The number of passes required depends on the steel thickness as well as the diameter of the electrode. Sufficient penetration into each adjacent pass is necessary for complete fusion of the weld.

POINTS TO REMEMBER

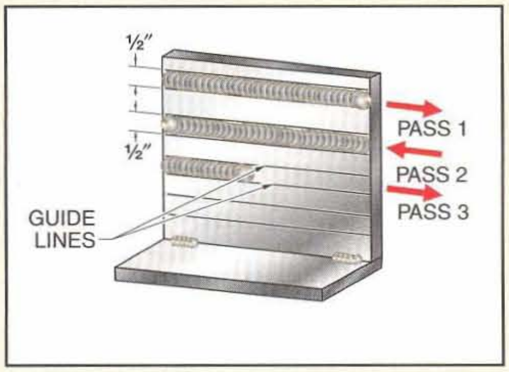
1. When welding in horizontal position, use a lower welding current and shorter arc length than when welding in flat position.
2. Do not allow the molten weld pool to sag, which can result in overlaps and undercuts.
3. When welding in horizontal position, hold the electrode at a work angle of 5° to 10° and a travel angle of 20°.
4. Use a slight weaving motion when welding in horizontal position.

Exercises

Depositing Straight Beads in Horizontal Position

exercise 1

1. Obtain a piece of ¼″ mild steel.
2. Draw a series of guide lines ½″ apart and the length of the workpiece.
3. Position the workpiece so the guide lines are in horizontal position. The workpiece may be clamped onto a positioner, if available, or tack welded to another workpiece or the workbench.
4. Adjust the welding machine to the correct current and, with a slight weaving motion, deposit beads between the guide lines. Start at the left edge of the first guide line and deposit a bead, working to the right edge.

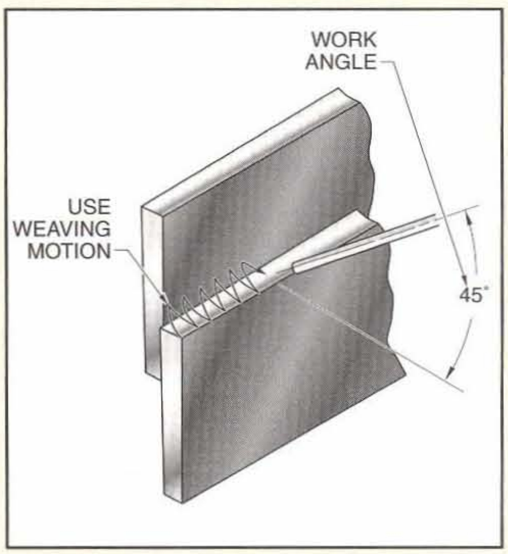


5. Move to the next guide line and reverse the direction of travel for the second bead.
6. Continue making beads in reverse directions until uniform beads can be made without overlapping and undercutting.

Welding a Single-Pass Lap Joint in Horizontal Position

exercise 2

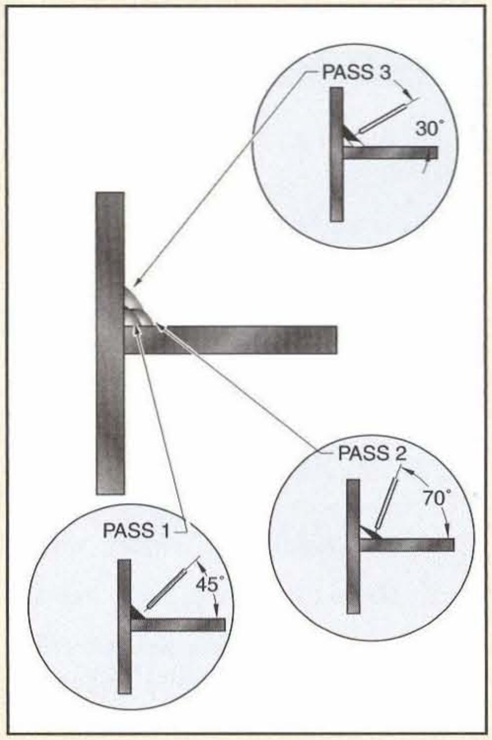
1. Obtain two pieces of ¼″ mild steel.
2. Form a lap joint and tack together.
3. Position the workpiece so the weld joint is in horizontal position.
4. Use a 45° work angle and deposit a single bead along the edge with a slight weaving motion. Watch the formation of the bead closely for any undercutting.



Welding a Multiple-Pass T-Joint in Horizontal Position

exercise 3

1. Obtain two pieces of ¼″ mild steel.
2. Form a T-joint with the workpieces at a 90° angle and tack together.
3. Position the workpiece so the weld joint is in horizontal position.
4. Angle the electrode to 45° and deposit a root pass along the joint without any weaving motion. Remove slag completely to ensure proper penetration.
5. Angle the electrode to 70° and deposit an intermediate weld pass. Use a slight weaving motion to control heat input, and make sure to penetrate the root bead and the base metal. A slight weaving motion should be used for the second pass. Remove slag completely.
6. Angle the electrode to 30° and deposit a third bead, using a slight weaving motion. The third bead should penetrate into the first and second beads, as well as the base metal. Complete penetration of the weld passes must be obtained, otherwise a weak weld results and the layers may separate.

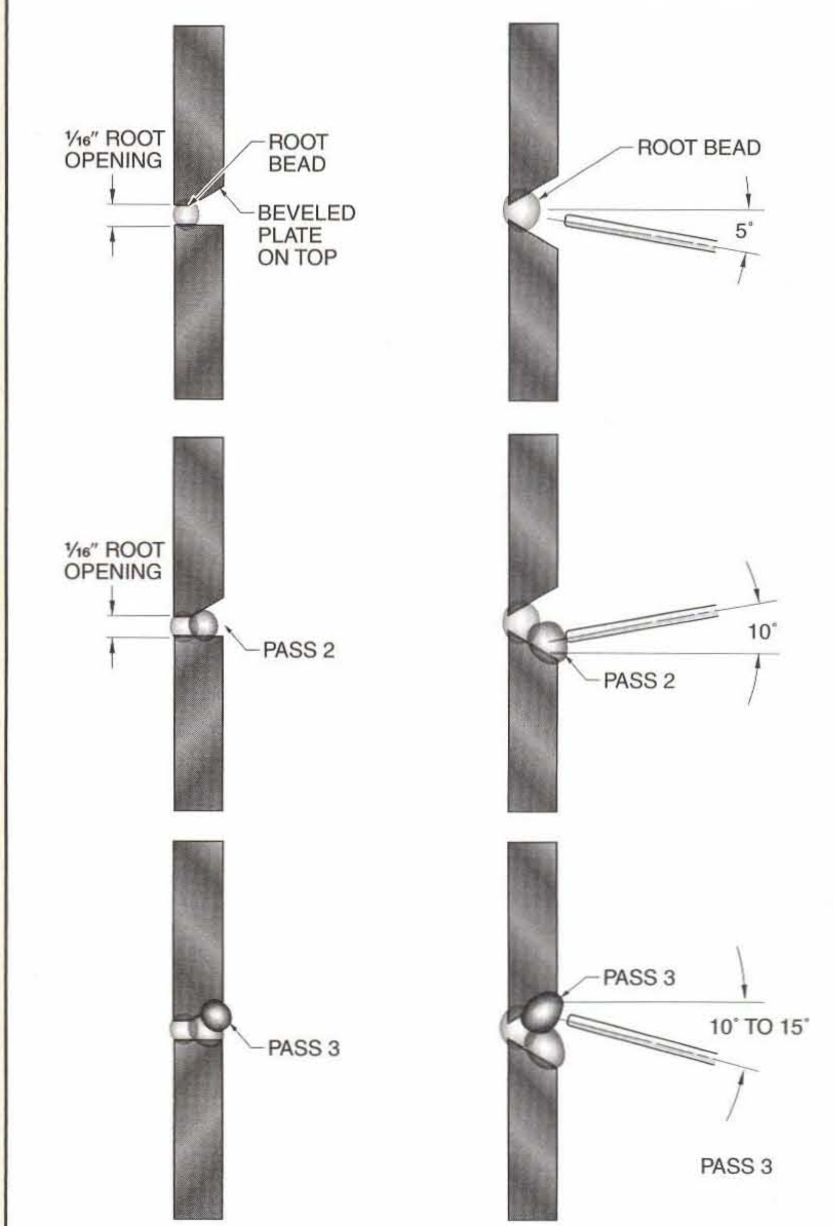


Welding a Multiple-Pass Butt Joint in Horizontal Position

exercise 4

1. Obtain two pieces of 1/4" mild steel and bevel the edge of one piece.
2. Form a butt joint, allowing a 1/16" root opening, and tack together.
3. Position the workpiece so the weld joint is in horizontal position with the beveled piece on top and the piece that is not beveled on the bottom.

   The flat edge of the non-beveled workpiece serves as a shelf, helping to prevent the weld pool from running out of the joint.
4. Deposit the root pass deep into the joint. Remove slag completely.
5. Deposit the intermediate weld pass(es), cleaning slag from weld after each pass. Each bead should penetrate the base metal and each previous pass.



End View
SINGLE BEVEL BUTT JOINT

End View
SINGLE-V BUTT JOINT

On some welding jobs, both edges of the joint are beveled to form a 60° groove angle. This is a single-V butt joint. Since a single-V butt joint does not provide a retaining shelf for the bead, as does a single bevel butt joint, more skill is required to produce a satisfactory weld.

On a wide joint, the weld is commonly finished with a cover pass to produce a smooth finish. A wide weaving motion that covers the entire area of the deposited beads is used to make the cover pass.

QUESTIONS FOR STUDY AND DISCUSSION

1. Why must a low current and a short arc length be used when welding in horizontal position?
2. What can be done to prevent overlaps on horizontal welds?
3. In what position should the electrode be held for welding horizontal beads?
4. Why should a weaving motion be used when making horizontal welds?
5. What determines the number of passes that should be made on a weld?
6. What groove angle is used when beveling the edges for a butt joint?
7. When is a cover pass used?
8. What work angles are required for each pass of a multiple-pass fillet T-joint weld in horizontal position?
9. What must be done between passes of a multiple-pass fillet T-joint to ensure proper penetration?

SMAW – Vertical Position

14

Shielded Metal Arc Welding (SMAW)

Welding in vertical position is frequently used for the fabrication of structures such as steel buildings, bridges, tanks, pipelines, ships, and machinery.

When welding in vertical position, gravity tends to pull down the molten metal from the weld pool. To prevent this from happening, fast-freeze or fill-freeze electrodes should be used. Weld pool control can also be achieved with proper electrode manipulation. Vertical welding is done by depositing beads using one of two methods, downhill welding or uphill welding.

DOWNHILL WELDING

A *vertical weld* is a weld with the axis of the weld approximately vertical. *Downhill welding* is welding with a downward progression. Downhill welding is commonly used for welding light-gauge metal because penetration is shallow. Downhill welding can be performed rapidly, which is important in production work. Although generally recommended for welding light-gauge materials because it does not cause melt-through, downhill welding can also be used for other metal thicknesses.

In downhill welding, maintain a travel angle of 15° to 30°. See Figure 14-1. Start at the top of the joint and move downward with little or no weaving motion. If a slight weave is necessary, manipulate the electrode so the crescent of the weave is at the top. On metal 1/4″ thick or more, uphill welding is more common.

When welding in vertical position, molten weld metal has a tendency to run out of the weld pool. Using a small diameter electrode reduces this tendency by reducing the weld pool size.

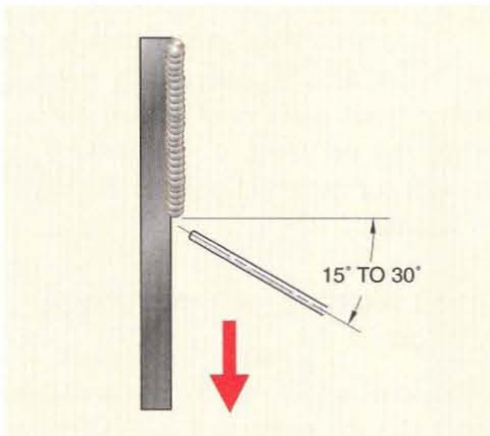


Figure 14-1. *Maintain a travel angle of 15° to 30° for downhill welding.*

When welding light-gauge metal in vertical position, downhill welding is used to control penetration.

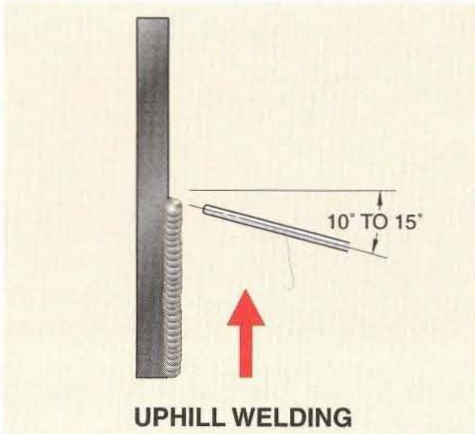
UPHILL WELDING

Uphill welding is welding with an upward progression. Uphill welding is commonly used on metal more than 1/4″ thick because deeper penetration can be obtained. Uphill welding also makes it possible to create a shelf for successive layers of beads.

For uphill welding, start with the electrode at a right angle to the workpiece. Position the electrode holder until the electrode forms a travel angle of 10° to 15°, pointing away from the direction of welding. See Figure 14-2.

On metal 1/4″ thick or more, uphill welding is commonly used to obtain the required penetration.

Figure 14-2. *Maintain a travel angle of 10° to 15° for uphill welding.*



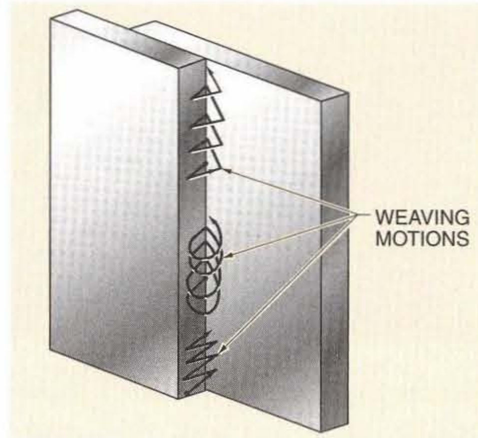


Figure 14-3. *A figure eight, rotary, or crescent weaving motion is used with uphill welding to control the width of the weld bead.*

Uphill Welding with a Whipping Motion

Uphill welding commonly uses fast-freeze electrodes with a whipping motion. *Whipping* is a manual welding technique in which the arc is moved quickly backward and forward as it progresses along the weld joint.

When whipping the electrode, do not break the arc, but simply pivot it with a wrist movement so that the arc is moved up ahead of the weld long enough for the weld pool in the crater to solidify.

Uphill Welding with a Weaving Motion

On grooved joints, deposit the root pass deep into the root opening.

Weld joint width varies depending on the metal thickness and edge preparation. The weld bead width must be adjusted to completely fill the required joint width. The width of the weld bead can be controlled using a weaving motion, such as the figure eight, rotary motion, or crescent. Each weaving motion produces a bead approximately twice the diameter of the electrode.

When using low-hydrogen electrodes and a weaving motion, the width of the weave pattern should not exceed 2½ times the diameter of the electrode.

The electrode is moved to allow penetration at the bottom of the stroke, and the upward motion momentarily removes the heat until the weld metal can solidify. See Figure 14-3.

The welder should pause at the toes of the weld. Pausing at the toes allows for complete fusion of the weld metal into the joint. The electrode should be moved quickly across the center of the weld to prevent excessive heat buildup.

E-7018 ELECTRODE WELDING TECHNIQUE

Although vertical welding techniques are generally applicable to all types of electrodes, a slight modification in procedure is advisable when using E-7018 electrodes.

In downhill welding, drag the electrode lightly, using a short arc. Do not use a long arc since the weld depends on the molten slag for shielding. A single, narrow bead or small weave is preferred to wide weave passes. Use lower current when welding with DC than with AC. Point the electrode directly into the joint and tip it forward a few degrees in the direction of travel.

With uphill welding, a triangular weaving motion often produces better results. Do not use a whipping motion or take the electrode out of the molten weld pool. Point the electrode directly into the joint and increase the travel angle slightly to permit the arc force to assist in controlling the weld pool. Current should be set toward the lower end of the recommended range.

POINTS TO REMEMBER

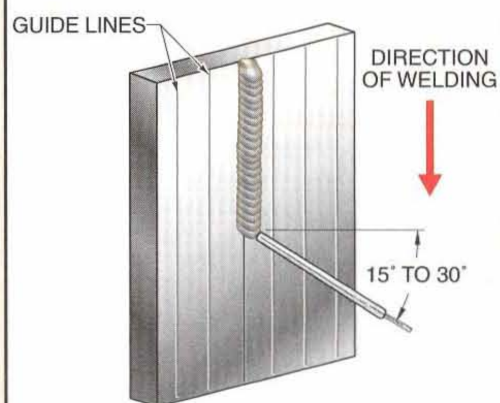
1. When welding light-gauge metal in vertical position, downhill welding is used to control penetration.
2. On metal ¼″ thick or more, uphill welding is commonly used to obtain the required penetration.
3. On grooved joints, deposit the root pass deep into the root opening.

Exercises

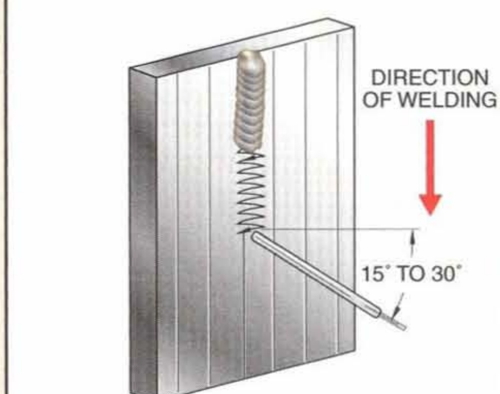
Depositing Beads in Vertical Position (Downhill)

exercise 1

1. Obtain a piece of ¼″ mild steel.
2. Draw a series of straight guide lines the length of the workpiece.
3. Position the workpiece so the guide lines are in vertical position.
4. Use E-6012 or E-6013 electrodes.
5. Start at the top of the workpiece with the electrode pointed upward at about a 15° to 30° angle. Keep the arc short and move the electrode downward to form the bead.
6. Maintain a travel speed that is just fast enough to prevent the molten weld pool and slag from running ahead of the crater. Do not use any weaving motion at the start.
7. Once straight, single beads can be deposited, weave the electrode slightly, with the crest at the top of the crater.



NO WEAVING MOTION

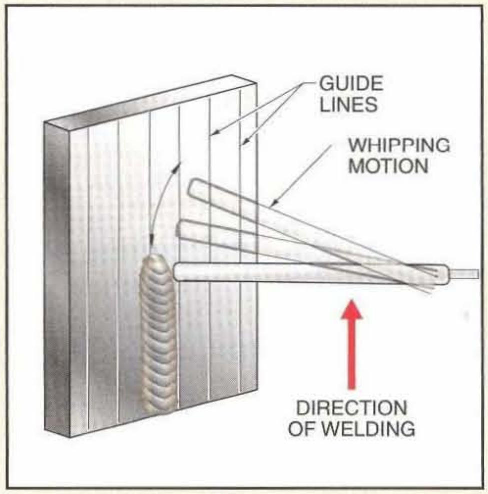


SLIGHT WEAVING MOTION

Depositing Beads in Vertical Position (Uphill)

exercise 2

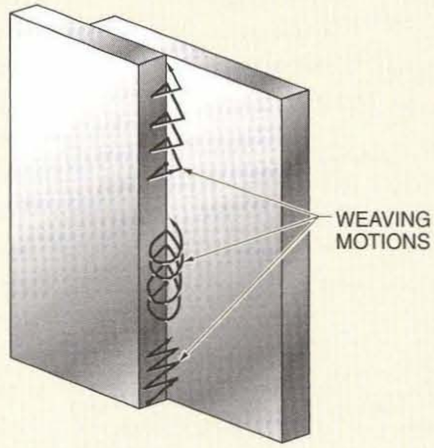
1. Obtain a piece of ¼″ mild steel.
2. Draw a series of straight guide lines the length of the workpiece.
3. Position the workpiece so the guide lines are in vertical position.
4. Use E-6010 or E-6011 electrodes for the necessary fast-freeze characteristics.
5. Start at the bottom of the workpiece with the electrode at a 10° to 15° angle. Move the electrode upward using a whipping motion.
6. Return the electrode to the crater and repeat the operation, working up along the drawn guide line to the top of the workpiece.
7. Do not break the arc while moving the electrode upward. Withdraw it just long enough to permit the deposited metal to solidify and form a shelf so additional metal can be deposited.



Welding a Lap Joint in Vertical Position (Uphill)

exercise 3

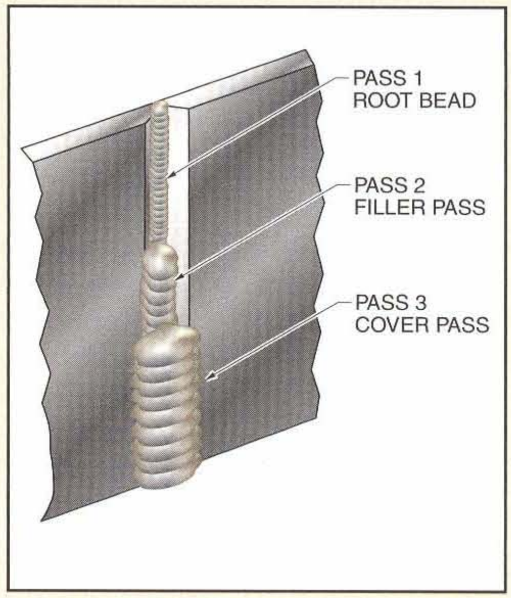
1. Obtain two pieces of ¼″ mild steel.
2. Form a lap joint and tack together.
3. Position the workpiece so the weld joint is in vertical position.
4. Start at the bottom of the workpiece and deposit a small root pass without any weaving motion.
5. Start at the bottom of the workpiece again and deposit a cover pass, using a weaving motion, from the bottom to the top.
6. Ensure that the cover pass completely penetrates the root bead.



Welding a Butt Joint in Vertical Position (Uphill)

exercise 4

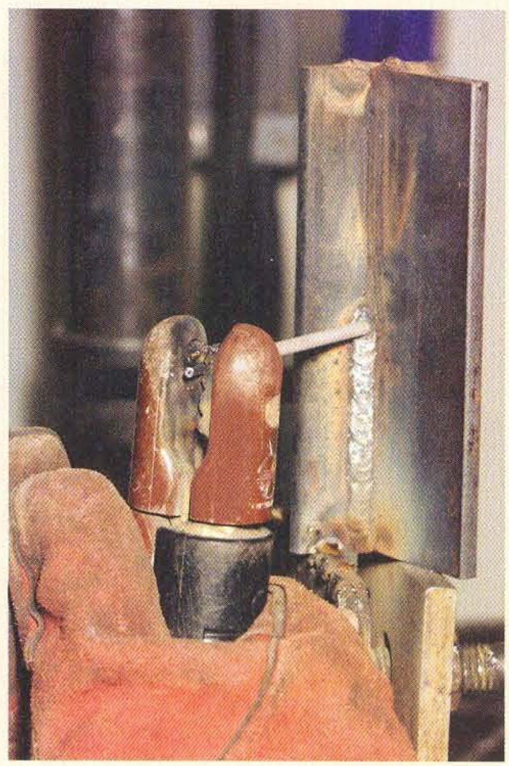
1. Obtain two pieces of ¼″ mild steel and bevel the edges to form a 60° groove angle.
2. Form a butt joint, with a ¹⁄₁₆″ root opening, and tack together.
3. Position the workpiece so the weld joint is in vertical position.
4. Start at the bottom of the workpiece and deposit a root pass. Remove slag completely.
5. Start at the bottom of the workpiece again and deposit an intermediate weld pass(es) as necessary to fill the root opening. Remove slag completely.
6. Finish the weld with a cover pass. Remove slag completely.



Welding a T-Joint in Vertical Position (Uphill)

exercise 5

1. Obtain two pieces of ¼″ mild steel.
2. Form a T-joint with the pieces at a 90° angle and tack together.
3. Position the workpiece so the weld joint is in vertical position.
4. Start at the bottom of the workpiece and deposit a narrow root pass. Remove slag completely.
5. Start at the bottom of the workpiece again and, using a weaving motion, deposit an intermediate weld pass. Remove slag completely.
6. On the opposite side, start at the bottom of the workpiece and deposit a narrow root pass. Remove slag completely.
7. Deposit an intermediate weld pass on the second side. Remove slag completely.
8. Check for complete penetration of each pass. Deposit a cover pass on each side. Remove slag completely.



QUESTIONS FOR STUDY AND DISCUSSION

1. In vertical welding, what can be done to prevent the weld pool from sagging?
2. Why is downhill welding more applicable to light-gauge metal?
3. In what position should the electrode be held in downhill welding?
4. What motions should be used in downhill welding?
5. How should the electrode be held when making an uphill weld?
6. What is the advantage of using a whipping motion on a vertical weld?
7. How can the width of a bead be increased on an uphill weld?
8. What direction of travel provides the most penetration when welding in vertical position?
9. What types of electrodes are commonly used in vertical welding?
10. What kind of weaving motion is used when welding uphill using an E-7018 electrode?
11. Which is faster, uphill welding or downhill welding?
12. What determines if a weld is in vertical position?
13. What types of electrodes can be used with a whipping motion?
14. What is the advantage of using a weaving motion when welding in vertical position?

SMAW – Overhead Position

15

Shielded Metal Arc Welding (SMAW)

Welding in overhead position is one of the most difficult welding operations to master. Although overhead welding is similar to flat position welding in technique, overhead welding is done from an awkward position and is greatly affected by gravity. In overhead position the weld pool has a tendency to drop, making it harder to secure a uniform bead and correct penetration. With practice it is possible to secure welds with the same quality as those made in other positions.

OVERHEAD WELDING

When overhead welding, the welder must be sure that the weld passes properly fill the weld joint. Molten metal can easily drop from the weld pool, causing uneven, inconsistent weld beads and incomplete penetration. Keep the arc length as short as possible when welding in overhead position to prevent molten metal from falling out of the weld pool. Beginning welders should practice welding beads in overhead position until a consistent bead can be laid repeatedly. When practicing welding in overhead position, a positioner is commonly used to secure workpieces. The positioner allows the welder to set the workpiece to any height or position. See Figure 15-1.

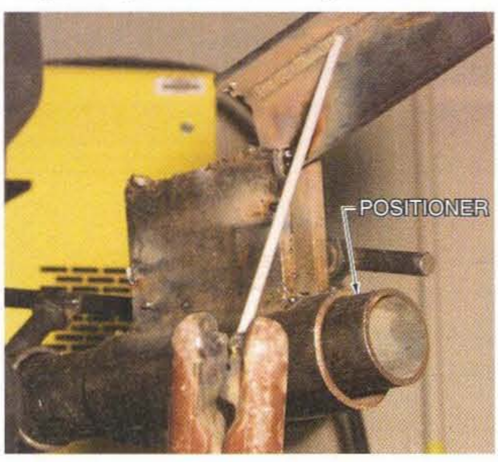
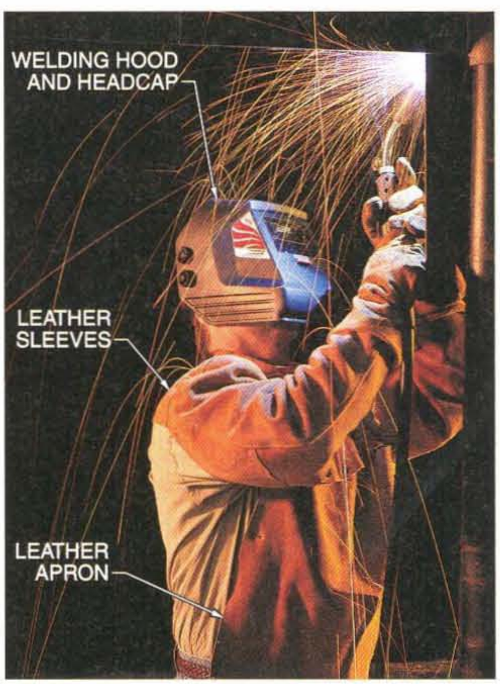


Figure 15-1. *A positioner allows work to be adjusted to any height or position.*

When overhead welding, personal protective clothing and equipment must be worn to protect against falling molten metal, slag, and sparks. A headcap, welding hood, and leather jacket or leather apron and leather sleeves should be worn to prevent slag and sparks from burning the skin. See Figure 15-2. Shirtsleeves should be rolled down and buttoned.

When welding in overhead position, keep the arc length as short as possible.



The Lincoln Electric Company

Figure 15-2. *Proper personal protective equipment must be worn when performing overhead welding to prevent injury.*

Overhead Welding Procedure

When welding in overhead position, use a fast-freeze electrode. To start welding, hold the electrode at a right angle to the joint. Hold the electrode at a work angle of 90° and a travel angle of 10° to 15°. See Figure 15-3.

A travel angle of 10° to 15° should be used for overhead welding.

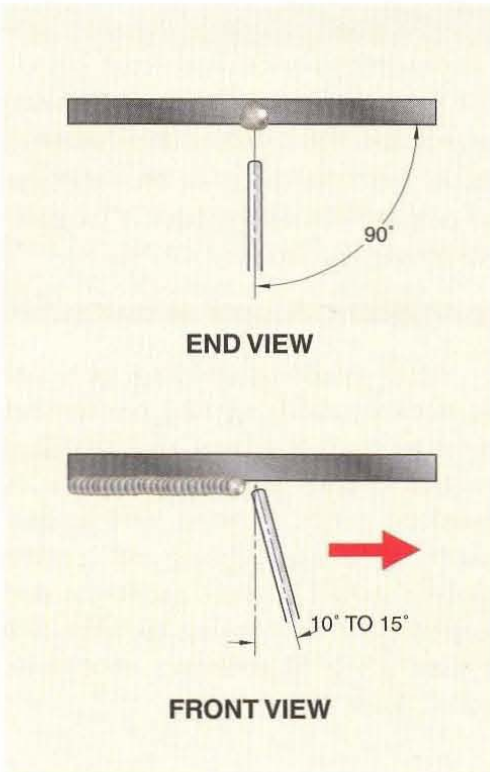


Figure 15-3. *For overhead welding, the electrode should be held at a work angle of 90° and a travel angle of 10° to 15°.*

⚠ WARNING

Molten metal can fall from the weld when welding in overhead position. Be sure sleeves are rolled down and a protective garment with a tight-fitting collar is zipped or buttoned up to the neck. Wear a headcap and heavy-duty shoes.

Grip the electrode holder so the knuckles of the hand are up and the palm is down. This prevents particles of molten metal from being caught in the palm of the glove and allows spatter to roll off the glove. The electrode holder can be held in one hand; however, sometimes welding is easier if it is held with both hands. See Figure 15-4. To avoid hot metal spatter, stand to the side rather than directly underneath the arc. The weight of the electrode lead can be minimized by draping it over a shoulder if welding in a standing position, or over a knee if in a sitting position.

Grip the electrode holder so the knuckles of the hand are up and the palm is down.

When welding in overhead position, stand to the side to avoid injury from hot metal spatter.

Drape the electrode lead over the shoulder if welding in a standing position, or over a knee if in a sitting position.

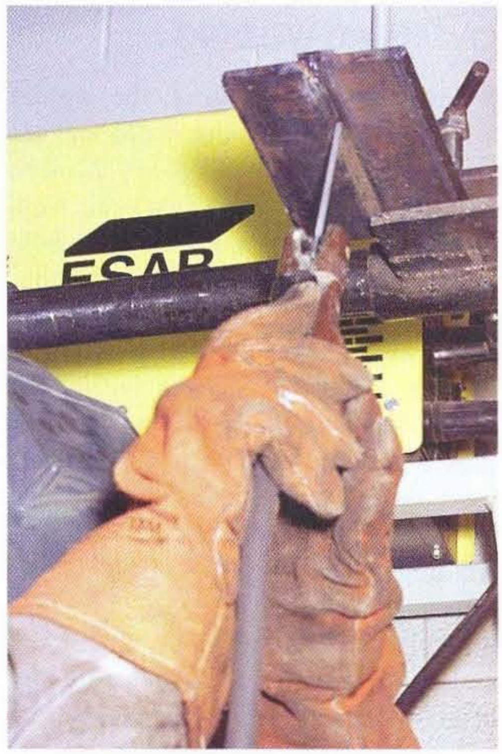


Figure 15-4. *A welder may use both hands to hold the electrode when welding in overhead position.*

POINTS TO REMEMBER

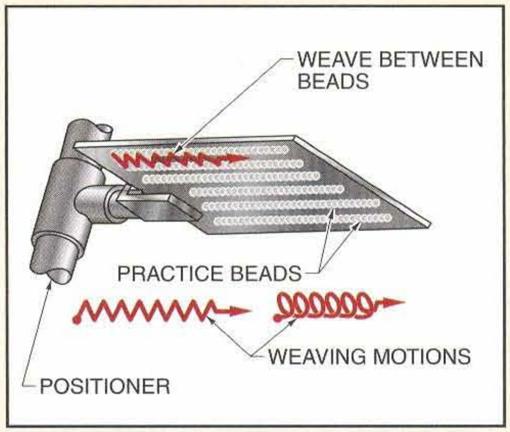
1. When welding in overhead position, keep the arc length as short as possible.
2. A travel angle of 10° to 15° should be used for overhead welding.
3. Grip the electrode holder so the knuckles of the hand are up and the palm is down.
4. When welding in overhead position stand to the side to avoid injury from hot metal spatter.
5. Drape the electrode lead over the shoulder if welding in a standing position, or over a knee if in a sitting position.

Exercises

Depositing Beads in Overhead Position

exercise 1

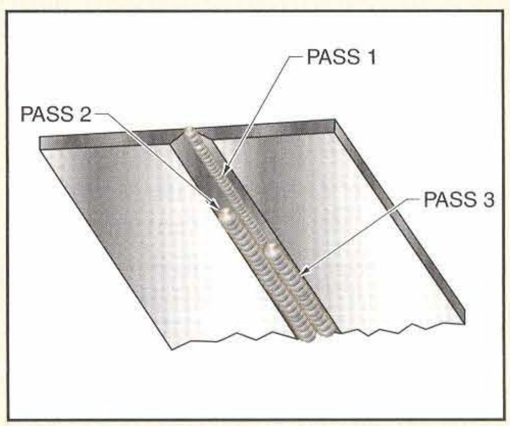
1. Obtain a piece of ¼″ mild steel.
2. Draw a series of guide lines on the workpiece, each line approximately ½″ apart.
3. Position the workpiece so the guide lines are in overhead position.
4. Set current as recommended for overhead welding. Strike an arc and form a weld pool as in flat position welding. Move the electrode along the weld joint, keeping the arc as short as possible.
5. Deposit a series of straight beads with no weaving motion. If necessary to prevent the weld pool from dropping, reduce the current slightly.
6. Practice depositing beads in one direction, then reverse and practice in the opposite direction.
7. Deposit beads using a weaving motion to fill in the space between the beads.



Welding a Multiple-Pass Single-V Butt Joint in Overhead Position

exercise 2

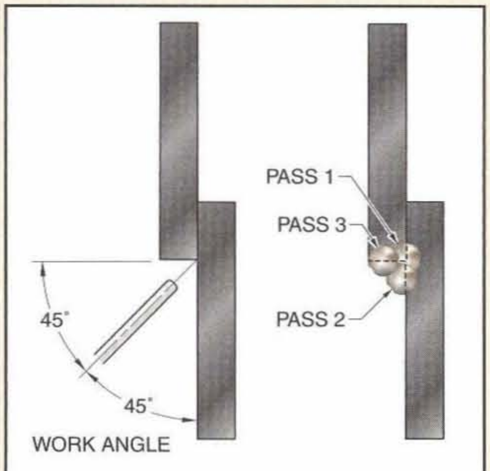
1. Obtain two pieces of ¼″ mild steel and bevel the edges.
2. Form a butt joint, with a 1⁄16″ root opening for expansion, and tack weld.
3. Position the workpiece so the weld joint is in overhead position.
4. Deposit a root pass in the root of the joint. Remove slag completely.
5. Deposit an intermediate weld pass(es) to cover the groove faces of the joint. Remove slag completely between passes.



Welding a Multiple-Pass Lap Joint in Overhead Position

exercise 3

1. Obtain two pieces of ¼″ mild steel.
2. Form a lap joint and tack together.
3. Position the workpiece so the weld joint is in overhead position.
4. Hold the electrode with a 45° work angle and a 15° travel angle.
5. Deposit a root pass in the root of the joint. Remove slag completely.
6. Deposit an intermediate weld pass, making sure the weld penetrates into the root bead and the bottom piece. Remove slag completely.
7. Deposit the cover pass, making sure the weld penetrates into the root bead and the top piece. Remove slag completely.

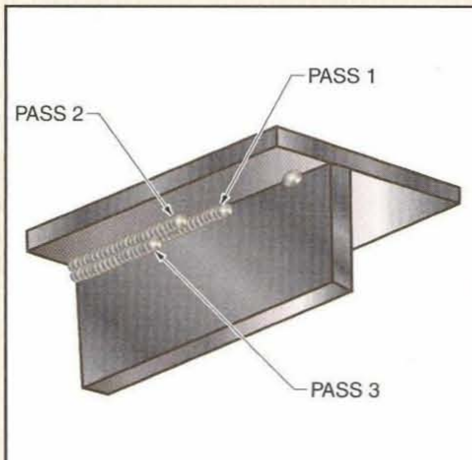


END VIEW

Welding a Multiple-Pass T-Joint in Overhead Position

exercise 4

1. Obtain two pieces of ¼″ mild steel.
2. Form a T-joint with the pieces at a 90° angle and tack together.
3. Position the workpiece so the weld joint is in overhead position.
4. Deposit a root pass in the root of the joint. Remove slag completely.
5. Deposit an intermediate weld pass and a cover pass. Remove slag completely between passes. Adjust the work angle of the electrode for each pass to ensure complete penetration.



QUESTIONS FOR STUDY AND DISCUSSION

1. Why is welding in overhead position more difficult than welding in other positions?
2. What is the recommended travel angle for overhead welding?
3. Why should the electrode holder be grasped so that the palm is facing down?
4. What should be done to prevent the weld pool from dropping?

16 GTAW–Equipment

Gas tungsten arc welding (GTAW) requires alternating current (AC) or direct current (DC). The choice of AC or DC current depends on the metal and weld requirements. Direct current electrode negative (DCEN) welding is commonly used for ferrous metals. AC high-frequency (ACHF) welding is commonly used for aluminum and nonferrous metals.

The GTAW process was developed in the late 1930s primarily for welding aluminum and magnesium in the aircraft industry. A breakthrough in GTAW occurred during World War II when ACHF was found to produce high-quality welds on aluminum. At one time, helium was used as a shielding gas, but was later replaced by the less expensive argon.

GAS TUNGSTEN ARC WELDING

Gas tungsten arc welding (GTAW) is an arc welding process in which a shielding gas protects the arc between a nonconsumable (does not become part of the weld) tungsten electrode and the weld area. See Figure 16-1. The GTAW process is also referred to as TIG (tungsten inert gas) welding.

Specially designed GTAW welding machines equipped with the necessary controls and attachments to provide the required current are available. The welding machine used for GTAW can provide either AC or DC current. GTAW requires precise current control, especially in the low range, to maintain a stable arc, particularly for welding light-gauge metals.

Gas tungsten arc welding (GTAW) can weld more types of metal and metal alloys than any other welding process.

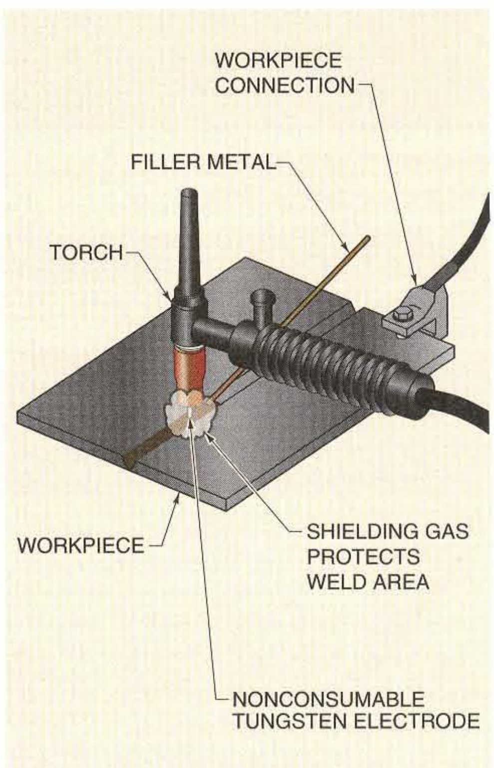


Figure 16-1. *Gas tungsten arc welding (GTAW) can be used without filler metal, although filler metal may be added to thick metal or to reinforce the joint on thin metals.*

A welding machine originally designed for use with SMAW must be derated to protect it from the effects of internal heating that occurs during GTAW. Derating is only necessary when using AC GTAW.

GTAW CURRENT SELECTION

Welding machines used for arc welding are classified by the output characteristics of voltage and current. Some metals are joined more easily with AC, while with other metals, better results are obtained with DC. The choice of using AC or DC current depends on the metal to be welded. See Figure 16-2.

Alternating Current

GTAW with AC current is used to weld aluminum and magnesium alloys. A cleaning action occurs with AC current because of a bombardment of positive charged gas ions that are attracted to the negative charged workpiece. Gas ions, as they strike the workpiece, break the oxide film and dislodge it from the surface. Generally speaking, better results are obtained when using AC current to weld aluminum and magnesium. No other metals require a cleaning action.

Welding machines specifically designated for GTAW do not have to be derated. *Derating* is a lowering of the current output level of an AC welding machine when being used for GTAW. Information regarding the welding processes a particular machine is rated for can be found on the welding machine nameplate or in the product literature.

AC welding machines not specifically designed for GTAW must have their output current levels derated when used for GTAW. A welding machine originally designed for use with SMAW must be derated to protect it from the effects of internal heating that occurs during GTAW. Derating is only necessary when using AC GTAW. Methods used to de-rate an AC welding machine are to lower the rated output current, lower the duty cycle, or both.

GTAW CURRENT SELECTION			
Metal	AC Current	DC Current	
	with High Frequency Stabilization	Electrode Negative	Electrode Positive
Magnesium up to ⅛″ thick	1	NR	2
Magnesium over 3/16″ thick	1	NR	NR
Magnesium Castings	1	NR	2
Aluminum	1	NR	2
Aluminum Castings	1	NR	NR
Stainless Steel up to .050″	1	2	NR
Stainless Steel .050″ or more	2	1	NR
Brass Alloys	2	1	NR
Silver	2	1	NR
Nickel Alloys	2	1	NR
Silver Cladding	1	NR	NR
Hardfacing	1	2	NR
Cast Iron	2	1	NR
Low-Carbon Steel .015″ to .030″	2	1	NR
Low-Carbon Steel .030″ to .125″	NR	1	NR
High-Carbon Steel .015″ to .030″	2	1	NR
High-Carbon Steel .030″ or more	2	1	NR
Deoxidized Copper up to .090″	NR	1	NR

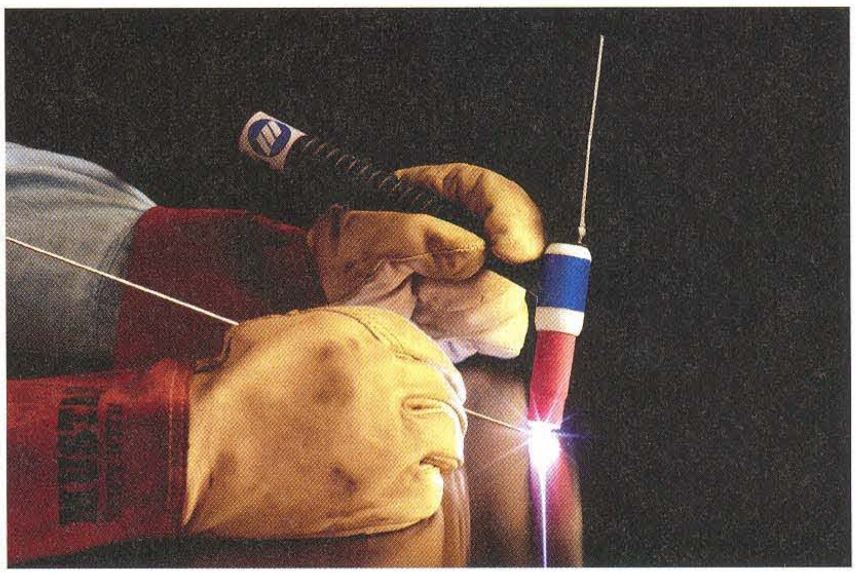
Key:
1. Excellent operation–best recommendation
2. Good operation–second recommendation
NR–not recommended

Figure 16-2. *The choice of using AC or DC current depends on the metal to be welded.*

1. Lower the rated output current. Derate the welding machine by 30% from its rated current. For example, a welding machine for SMAW is rated at 200 A, 60% duty cycle. For GTAW, the rated output current is lowered 30% (200 A × .30 = 60 A; 200 – 60 = 140 A). The derated current output is 140 A. With this method, the duty cycle for GTAW is the same as for SMAW.
2. Lower the duty cycle. See Figure 16-3. Find the duty cycle rating of the welding machine (found on the welding machine nameplate), multiply the rated duty cycle by the predetermined rated amps percentage to find 100% duty cycle for non-GTAW applications; multiply the non-GTAW rating by 70% to de-rate the amps to 100% duty cycle for GTAW.

Alternating Current High-Frequency. AC provides a combination of the penetrating qualities of DCEN and the cleaning action of DCEP. Half of the complete AC cycle is electrode negative and the other half is electrode positive. However, when welding using AC current, oxides, scale, and moisture on the workpiece tend to prevent the full flow of current in the DCEP half of the cycle. If no current flowed in the electrode positive direction during welding, the partial or complete stoppage of current flow (rectification) would cause the arc to be unstable and possibly extinguish. Alternating current high-frequency (ACHF) welding uses a rapid alternation of electrode negative and electrode positive. The faster alternation of electrode negative and electrode positive during ACHF permits the arc to be maintained without interruption. See Figure 16-4.

ACHF provides a combination of the penetrating qualities of DCEN and the cleaning action of DCEP.



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Current selection for GTAW is based on the type of metal to be welded.

Derating Duty Cycles
Figure 16-3

WELDING MACHINE			NON-GTAW APPLICATIONS	AC GTAW APPLICATIONS		
Duty Cycle	Rated Amps times:		Duty Cycle	Derated Amps times:		Derated Duty Cycle
60%	75%	=	100%	70%	=	100%
50%	70%	=	100%	70%	=	100%
40%	55%	=	100%	70%	=	100%
30%	50%	=	100%	70%	=	100%
20%	45%	=	100%	70%	=	100%

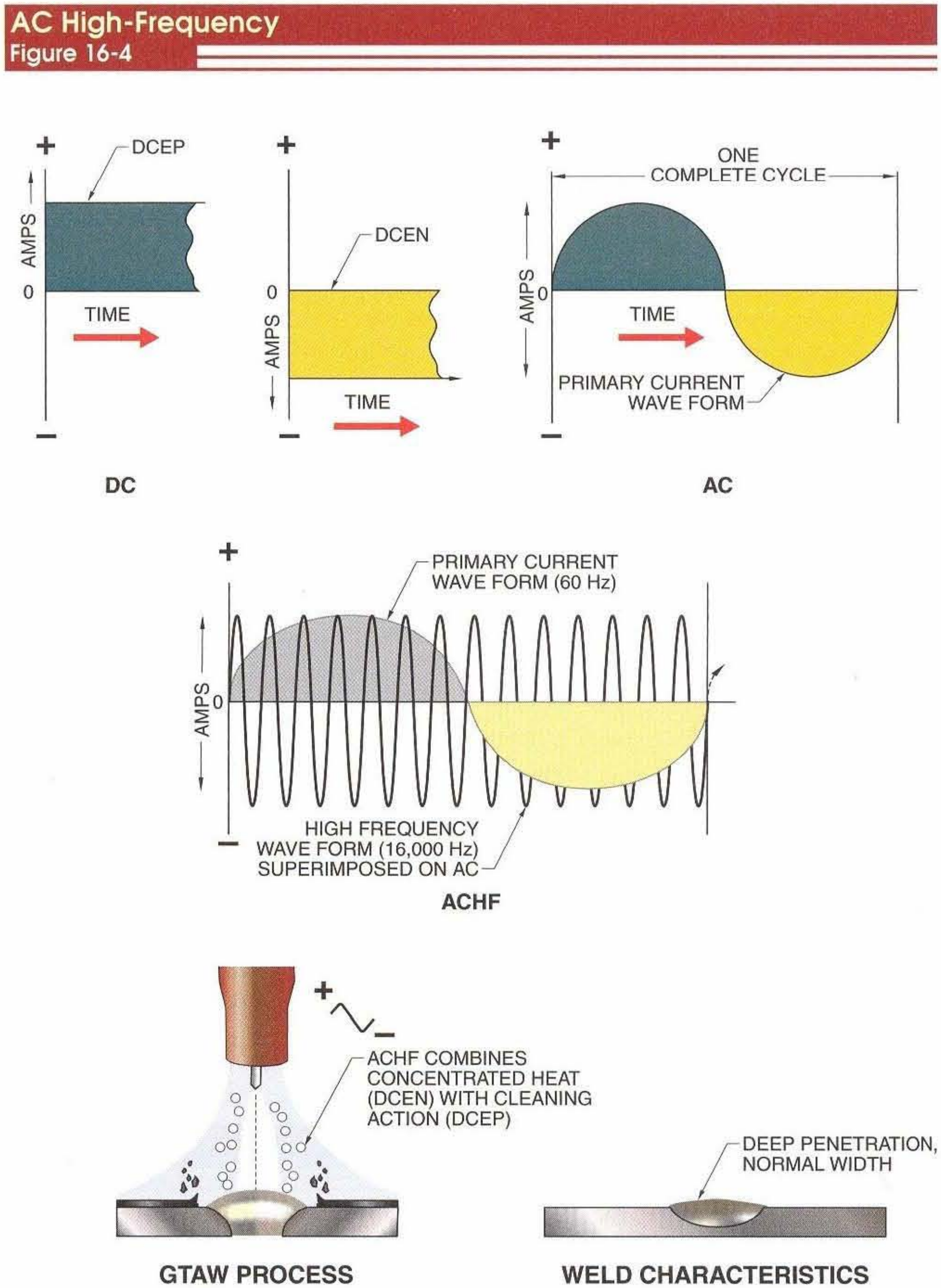
Find the duty cycle rating of the welding machine in use (found on the welding machine nameplate). Multiply the rated amps by the predetermined percentage to find 100% duty cycle for non-GTAW applications. Multiply by 70% to derate the amps to the 100% duty cycle for GTAW.

For example, what is the 100% derated duty cycle for a 200 A, 60% duty cycle welding machine used for non-GTAW applications? Used for AC GTAW applications?

200 × .75 = 150 A (100% duty cycle for non-GTAW applications)
150 × .70 = 105 A (100% duty cycle for AC GTAW applications)

Figure 16-3. *AC welding machines can be derated to provide a 100% duty cycle when using GTAW.*

Figure 16-4. *In AC, half of the complete AC cycle is electrode negative and half is electrode positive. Alternating current, high-frequency (ACHF) combines the beneficial qualities of DCEN and DCEP.*



Direct Current

Direct current (DC) is an electrical current that flows in one direction only. Direct current must be electrode negative (DCEN) or electrode positive (DCEP). With DCEN, electron flow from the electrode to the workpiece creates heat at the workpiece. With DCEP, electron flow from the workpiece to the electrode creates heat at the electrode. See Figure 16-5. The term DCEN replaces the term straight polarity. The term DCEP replaces the term reverse polarity.

To prevent confusion about terminal connections on the welding machine when using DC current, remember the abbreviations for two words, senator (SEN–Straight Electrode Negative) and representative (REP–Reverse Electrode Positive).

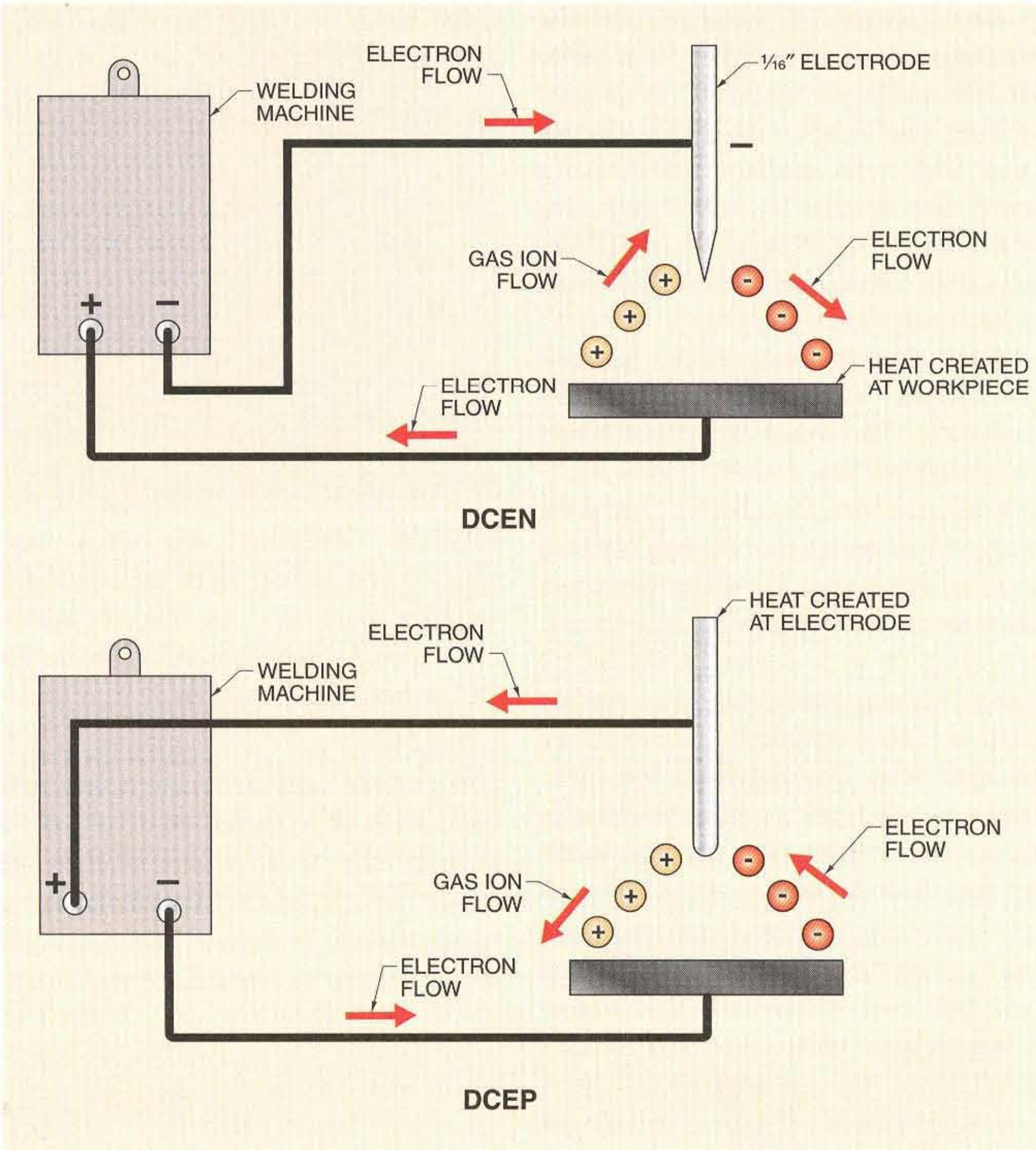


Figure 16-5. *With DCEN, electron flow from the electrode to the workpiece creates more heat at the workpiece. With DCEP, electron flow from the workpiece to the electrode creates more heat at the electrode.*

Direct Current Electrode Negative (DCEN). Most ferrous metals are welded using direct current electrode negative (DCEN). Nonferrous metals, except aluminum and magnesium, can also be welded with DCEN. DCEN is used for welding most metals because it produces deep penetration into the metal. When the welding machine is set for DCEN, electron flow is from the electrode to the workpiece, creating considerable concentrated heat in the workpiece. Additionally, welding is more rapid, there is less distortion of the base metal, and the weld pool is deeper and narrower than with DCEP. Since more heat is directed at the workpiece, smaller diameter electrodes can be used.

Direct Current Electrode Positive (DCEP). When the welding machine is set for direct current electrode positive (DCEP), the flow of electrons is from the workpiece to the electrode, causing a greater concentration of heat at the electrode. The intense heat at the electrode with DCEP requires a larger diameter electrode than DCEN. For example, a 1/16″ diameter tungsten electrode normally can conduct approximately 125 A in a DCEN circuit. However, if DCEP is used with 125 A, the tip of the electrode melts off. When welding using DCEP, a 1/4″ diameter electrode is required to conduct 125 A of welding current.

In the GTAW process, DCEN is used for welding most ferrous metals because it produces deep penetration into the metal.

DCEP is rarely used in GTAW except in special aluminum and magnesium applications.

The type of DC current used for welding affects the shape of the weld. DCEN results in a narrow, deep penetrating weld whereas DCEP results in a wide and shallow penetrating weld. See Figure 16-6. For this reason DCEP is rarely used in GTAW except in special aluminum and magnesium applications.

Aluminum and magnesium form an oxide layer when exposed to the atmosphere. The oxide layer that forms on aluminum has a much higher melting point than the aluminum to be welded and must be removed before welding can begin. The oxide layer can be removed with a chemical cleaner, by filing, or with a wire brush. DCEP has a cleaning action that more readily removes the oxide layer. The positive charged ions flowing from the electrode to the workpiece strike the workpiece with enough force to break up the oxide layer.

CONSTANT-CURRENT WELDING MACHINES

A constant-current welding machine maintains a nearly constant current flow in the weld circuit, no matter how the voltage varies. See Figure 16-7. Generally, the welding current remains the same throughout the welding process; however, as the arc voltage decreases, the current may increase slightly.

INVERTER WELDING MACHINES

Inverter welding machines are smaller and lighter than conventional welding machines. An inverter welding machine rectifies AC current to DC current and switches it to a high-frequency AC current, which is then output as DC current. The AC high-frequency current is rectified to provide smooth DC current output at the set current and voltage values.

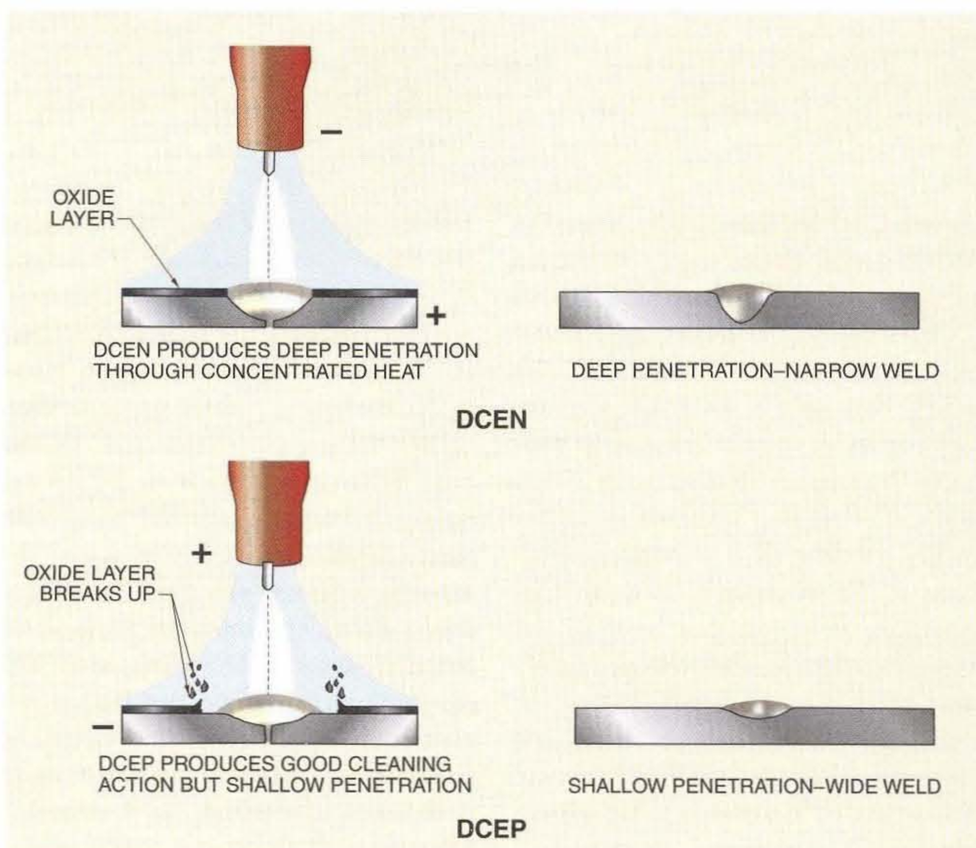


Figure 16-6. *The type of DC current affects the shape of the weld. DCEN produces a narrow, deep weld whereas DCEP forms a wide and shallow weld.*

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Figure 16-7. *A constant-current welding machine maintains a nearly constant current flow during welding.*

Inverter welding machines have a faster reaction time than transformer/rectifier constant-current welding machines because there are no transformers or inductors in the inverter to slow reaction time. Constant-current welding machines operate at 50 hertz (Hz) or 60 Hz, requiring one or two cycles to react.

GTAW EQUIPMENT

To make a quality weld, the proper GTAW equipment must be used. A tungsten electrode directs the arc established between the welding machine and the workpiece. When GTAW is properly performed, the tungsten electrode does not melt. The workpiece at the arc melts, forming a molten weld pool.

Shielding gas, usually argon, protects the weld area against contamination from nitrogen and oxygen in the atmosphere. The GTAW process can be used to weld with or without filler metal. Thick metals typically require that filler metal be added to fill the joint. Normally, filler metal is not required for thin metals; however, filler metal may be added to thin metals when joint reinforcement is required. GTAW welding machines also include controls for shielding gas and cooling water flow. GTAW equipment typically includes a torch, a tungsten electrode, and shielding gas. See Figure 16-8.

Torch

A GTAW torch is designed to hold the tungsten electrode, direct the shielding gas to the weld, and allow easy positioning of the torch. Torches can be either air-cooled or water-cooled. Air-cooled torches are designed for welding at low operator duty cycles on light-gauge metals when low current values are used. Air-cooled torches are generally used for welding up to 200 A.

A water-cooled torch uses a stream of water circulating around the torch to prevent overheating. A water circulator on water-cooled torches provides the flow of cooling water to and from the torch to maintain a safe torch operating temperature. The water circulator consists of a tank, pump, feed supply line, and return line. The flow rate of cooling water required depends on the welding operation. Torch manufacturers provide recommended settings for shielding gas flow and cooling water flow. Water-cooled torches are recommended when welding requires currents over 200 A.

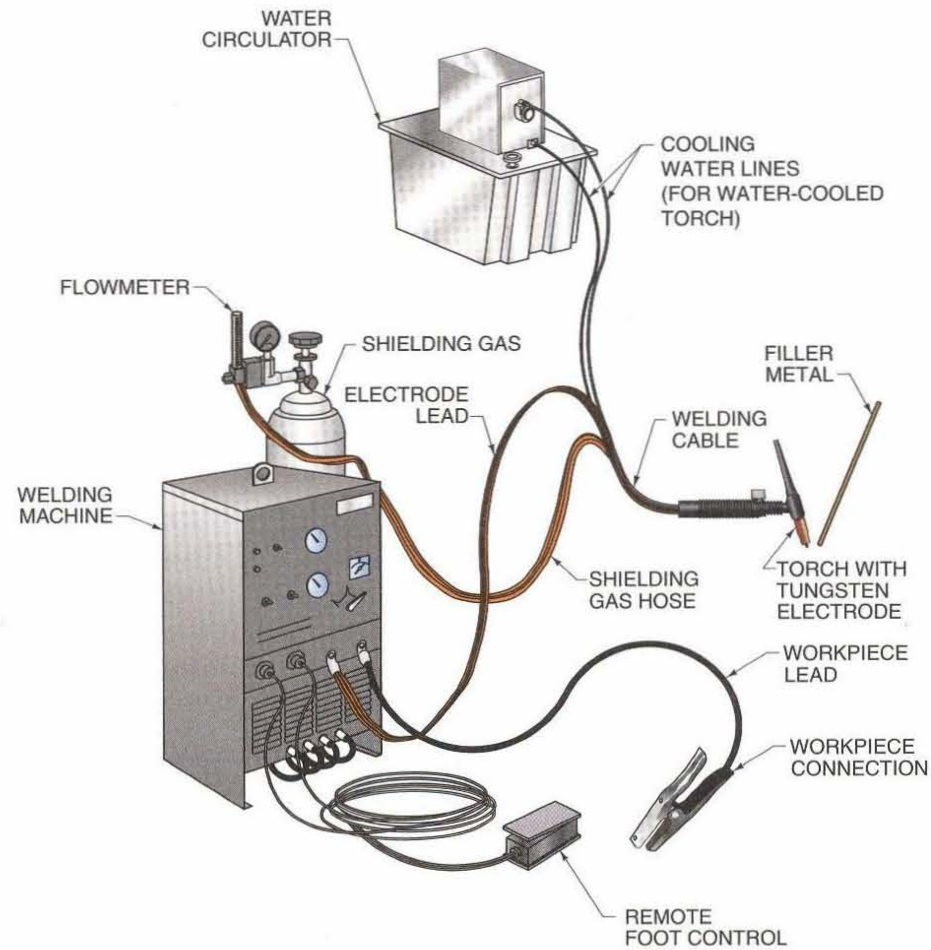
A water-cooled torch is recommended when using currents over 200 A. Ensure cooling water is flowing before welding.

Welding cables conduct welding current and direct the shielding gas to the torch. The welding cable on a water-cooled torch also transports cooling water.

A control switch controls the flow of both current and shielding gas. A timer that maintains gas flow after the weld current is stopped (postflow) is used to protect the weld area from atmospheric contamination. Depending on the equipment, control of current and shielding gas is controlled by finger, hand, or foot. By gradually decreasing the current, it is possible to fill the crater and control heat more effectively.

Figure 16-8. *Equipment required for GTAW typically includes a torch, tungsten electrode, shielding gas, filler metal, water circulator, and flowmeter, in addition to the welding machine.*

GTAW Equipment
Figure 16-8



Gas nozzles that are too small for the welding task may overheat, crack, or deteriorate rapidly.

The tungsten electrode that supplies the welding current is held rigidly in the torch by means of a collet that screws into the torch. The collet is contained within a collet body that screws into the torch body. A variety of collet sizes are available so different diameter electrodes can be used. The diameter of the tungsten electrode used determines the size of the collet and collet body required. A gas nozzle is screwed into the torch head or snapped into place. A properly sized gas nozzle should be used to ensure the correct shielding gas stream. The gas nozzle directs the shielding gas to the weld zone. See Figure 16-9.

Gas nozzles vary in size and are interchangeable to accommodate a variety of gas flow rates. The required size (orifice diameter) depends on the type and size of the torch and the diameter of the electrode. See Figure 16-10.

Some gas nozzles are equipped with a gas lens to eliminate turbulence in the gas stream, which tends to pull in air and cause weld contamination. Gas lenses have a permeable barrier of concentric fine-mesh stainless steel screens that fit into the gas nozzle. See Figure 16-11.

Tungsten electrode lengths are determined by the welding application and the type of torch used. Standard tungsten electrode lengths are 3″, 6″, 7″, 12″, 18″, and 24″.

GTAW Torches
Figure 16-9

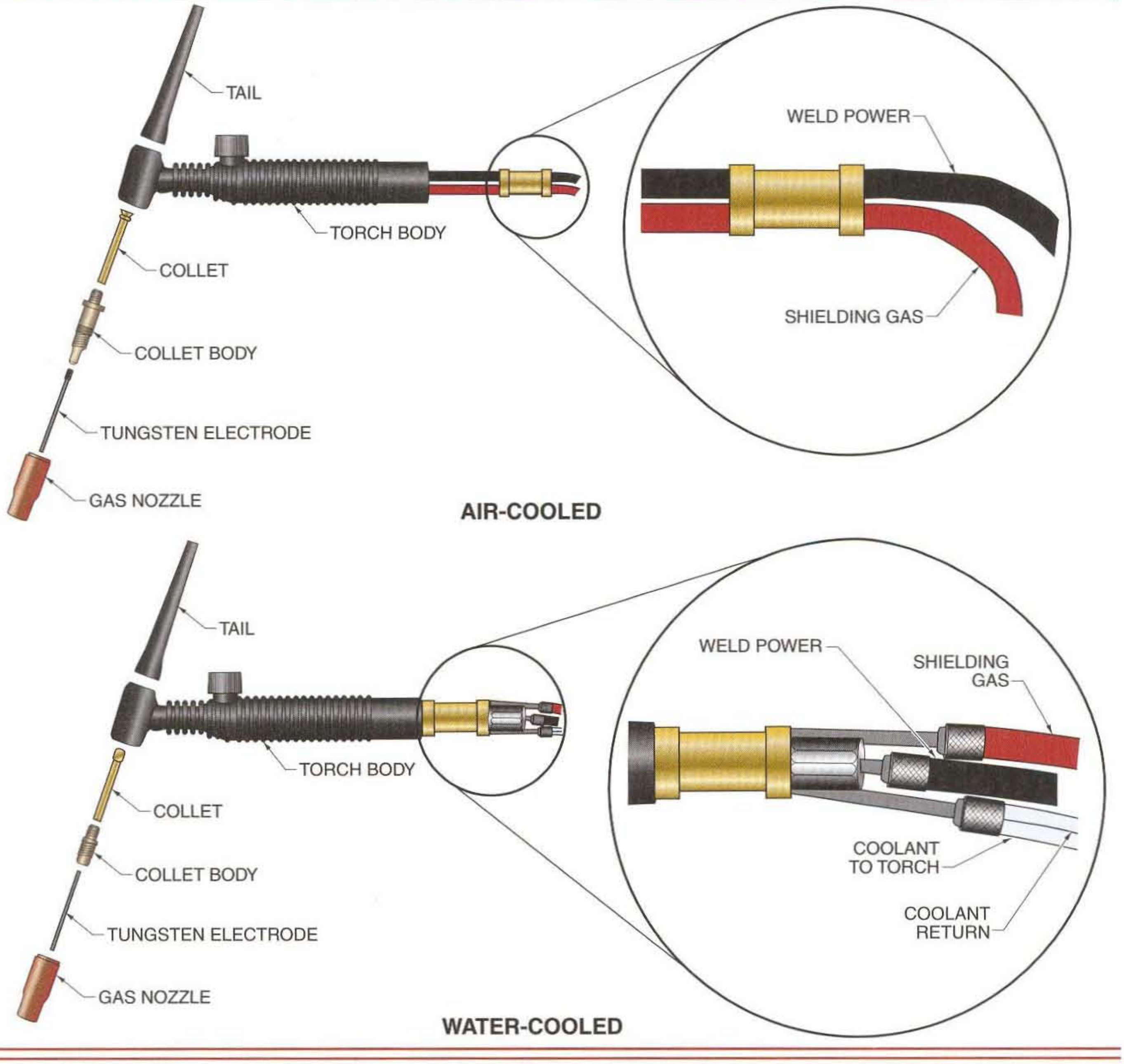


Figure 16-9. *An air-cooled torch is used for welding light-gauge metals. A water-cooled torch prevents overheating when welding requires current above 200 A.*

GAS NOZZLE SIZES		
Metal Thickness	Tungsten Electrode Diameter*	Gas Nozzle Orifice Diameter*
1/16	1/16	1/4 – 3/8
1/8	3/32	3/8 – 7/16
3/16	3/32	7/16 – 1/2
1/4	3/32 or 1/8	1/2 – 3/4

* in in.

Figure 16-10. *The required orifice diameter for a gas nozzle depends on the type and size of the torch selected for the metal thickness, and the diameter of the electrode.*

Tungsten Electrode

Electrodes used for GTAW are made of tungsten. Tungsten, which has the highest melting point of all metals, is virtually nonconsumable when correct welding procedures are followed. The electrode is used only to create the arc, it is not consumed in the weld. See Figure 16-12. Incorrect current, diameter, excessive current, and/or electrode contamination can result in melting or deformation of the tungsten electrode.

Figure 16-11. *A gas lens in the gas nozzle eliminates turbulence in the shielding gas stream.*

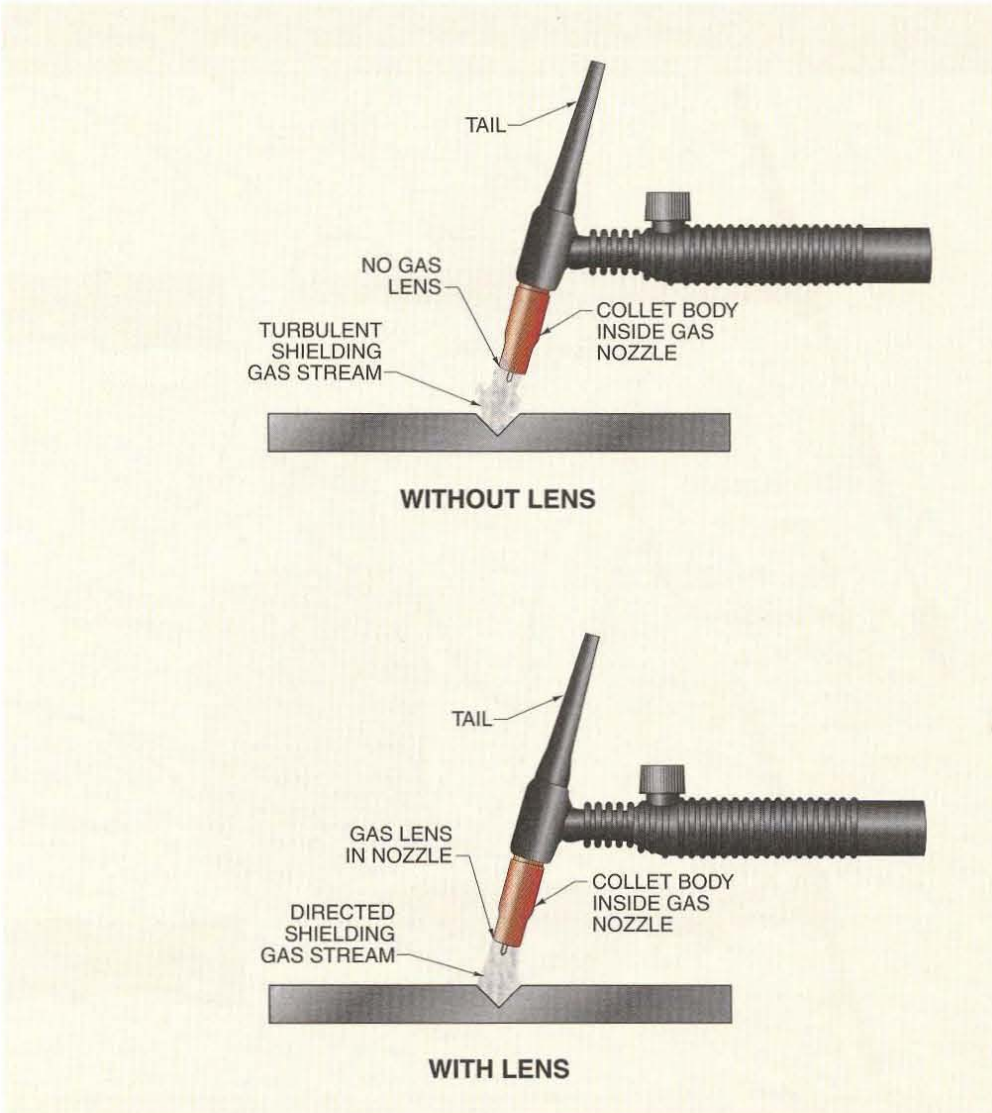
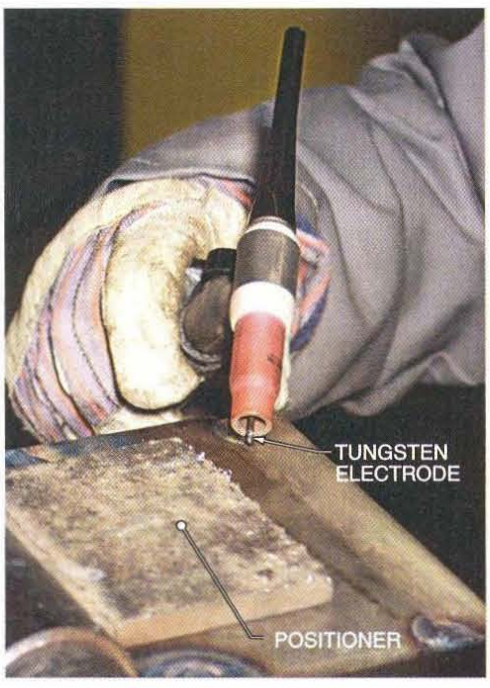


Figure 16-12. *In GTAW, a tungsten electrode is used to provide the arc for welding; it is not consumed in the weld.*



Tungsten electrode diameters are sized by decimal (.010″, .020″, .040″) or by fraction ($^{1}/_{16}$″, $^{3}/_{32}$″, $^{1}/_{8}$″, and $^{5}/_{32}$″). The diameter of the electrode selected for a welding operation is determined by the required welding current. Small-diameter tungsten electrodes may be used with low current. Large-diameter tungsten electrodes are required when using high current. See Appendix.

Electrodes can be composed of pure tungsten or alloyed tungsten. Pure tungsten electrodes are the least expensive and are identified with a green marking. Pure tungsten electrodes are commonly used to weld aluminum and magnesium and are designed for use with AC current.

Alloyed tungsten electrodes usually contain 1% or 2% thorium or zirconium and are commonly used on mild steel and stainless steel. One percent thoria tungsten electrodes are identified with a yellow marking. Two percent thoria tungsten electrodes are identified with a red marking. Thoriated tungsten electrodes can give off hazardous fumes. Always ensure proper ventilation during welding.

Thoriated tungsten electrodes conduct higher currents, provide a more stable arc than a pure tungsten electrode, keep the tip cooler at a given current level, minimize movement of the arc around the electrode tip, permit easier arc starting, and prevent contamination of the electrode through accidental contact with the workpiece. Thoriated tungsten electrodes are designed for use with DCEN.

A 2% thoria electrode is used primarily for critical sheet metal weldments in the aircraft and aerospace industries. Although 2% thoria electrodes normally maintain a formed point longer than the 1% type, they have little advantage over the 1% thoria electrode for most steel welds.

Electrode Shape. To produce a quality weld, the tungsten electrode is prepared to the correct shape. A pointed-end electrode is used with DCEN current and a hemispherical-tip electrode is used with AC current. See Figure 16-13. The prepared end is opposite to the end with the color marking to allow for future identification of the electrode. The electrode must also be kept straight to prevent the gas flow from being off-center from the arc.

Stickout. Stickout for GTAW is the length of tungsten electrode that extends beyond the end of the gas nozzle. The tungsten electrode stickout must be properly adjusted when welding with GTAW and is determined by the type of weld joint and the position of welding. Typically the tungsten electrode should extend ⅛″ to 3⁄16″ beyond the end of the gas nozzle for groove welds on butt joints and ¼″ to ⅜″ for fillet welds. Current must be shut OFF when adjusting electrode stickout.

The diameter of the electrode selected for a welding operation is determined by the required welding current.

Before starting to weld, ensure that the tungsten electrode has the proper stickout beyond the end of the gas nozzle.

Shielding Gas

The primary consideration in any welding operation is to produce a weld that has the same properties as the base metal. Such a weld can only be made if the molten weld pool is completely protected from the atmosphere during the welding process. Shielding gas prevents nitrogen and oxygen in the atmosphere from entering and contaminating the weld pool. This results in welds that are stronger, more ductile, and more corrosion-resistant than welds made by most other welding processes. Since the filler metal is not coated with flux, traces of flux do not need to be removed from the weld.

The type and amount of shielding gas used is determined by current, type of weld, base metal, and welding conditions.

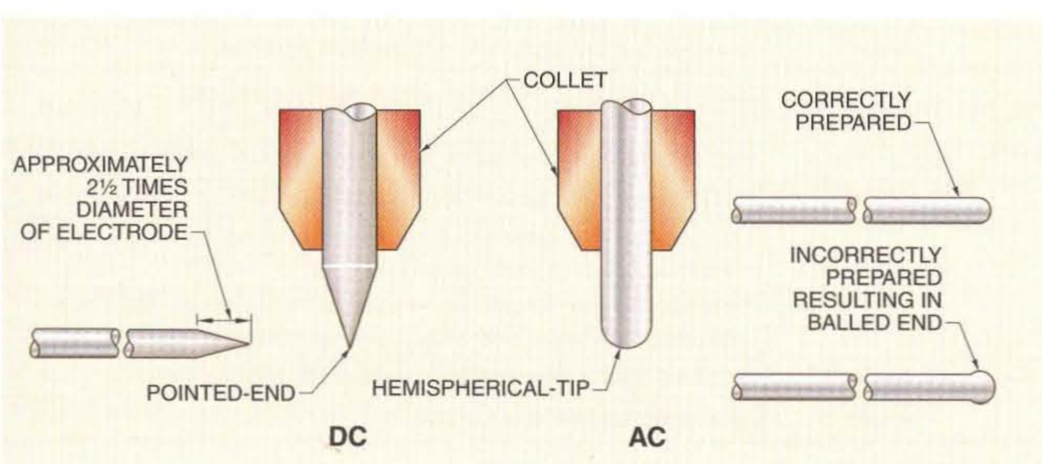


Figure 16-13. *Welding with DC current requires an electrode with a pointed tip. Welding with AC current requires a hemispherical-tip electrode.*

Argon is the most commonly used shielding gas, and is regulated by a flowmeter.

Shielding gas is required before, during, and after the welding operation. Before welding, shielding gas is directed to the weld area to displace the air in the weld area. During welding, shielding gas flow continues to protect the weld from atmospheric contamination. After welding, a postflow timer controls the time shielding gas flows after the arc is stopped to protect the weld until it is no longer subject to contamination.

Shielding gases used for GTAW are inert gases such as argon or helium, or a mixture of argon and helium. See Figure 16-14. An *inert gas* is a gas that does not readily combine with other elements. The type and amount of shielding gas used is determined by current, type of weld, base metal, and welding conditions.

Argon is the most commonly used shielding gas. Argon is heavier than air, which facilitates efficient coverage of the weld area so less gas is required, which makes it more economical than helium. Argon gas is easier to control in drafty conditions and it is easier to establish an arc at lower current setting.

GTAW SHIELDING GASES

Material	Type	Preferred Gas	Remarks
Aluminum	Manual Welding	Argon	Better arc starting, cleaning action, and weld quality; lower gas consumption
		Helium	Higher welding speed possible
	Machine Welding	Argon-Helium	Better weld quality, lower gas flow than required with straight helium
Magnesium	To 1/16″	Helium	Controlled penetration
	Over 1/16″	Argon	Excellent cleaning, ease of manipulation, low gas flow
Mild Steel	To 1/8″	Argon	Ease of manipulation, freedom from overheating
	Over 1/8″	Argon	Produces high quality welds
	Spot Welding	Argon	Generally preferred for longer electrode life Better weld nugget contour
		Argon-Helium	Ease of starting, lower gas flow Helium addition improves penetration on heavy-gauge metal
	Manual Welding	Argon	Better weld pool control, especially for position welding
Stainless Steel	Machine Welding	Argon	Permits controlled penetration on light-gauge material (up to 14 gauge)
		Argon-Helium	Higher heat input, higher welding speed possible on heavier gauge metal
		Argon-Hydrogen (95%-5%)	Prevents undercutting, produces desirable weld contour at low current level, requires less gas flow
		Helium	Provides highest heat input and deepest penetration
Copper & Nickel and thier Alloys		Argon	Ease in controlling weld pool, and ensuring adequate penetration and bead contour on light-gauge metal
		Argon-Helium	Higher heat input to offset high heat conductivity of heavier gauges
		Helium	Highest heat input for high welding speed on heavy metal sections
Titanium		Argon	Low gas flow rate minimizes turbulence and air contamination of weld; improved metal transfer; improved HAZ
		Helium	Better penetration for manual welding of thick sections (inert gas backing required to shield back of weld against contamination)
Silicon Bronze		Argon	Reduces cracking tendency on cooling ("hot shortness")
Aluminum Bronze		Argon	Less penetration of base metal

Figure 16-14. *Argon or a mixture of argon-helium may be used as shielding gases for GTAW.*

Argon is supplied in steel cylinders containing approximately 330 cu ft at a pressure of 2000 psi. A single- or two-stage pressure regulator or a specially designed regulator containing a flowmeter is used to control the gas flow. The flowmeter is calibrated to show the flow of gas in either cubic feet per hour (cfh) or liters per minute (lpm). The flow of argon to the torch is controlled by turning the adjusting screw on the flowmeter. See Figure 16-15. The rate of flow required depends on the weld application. As the adjusting screw is turned counterclockwise, the gas flow increases and raises a visible stainless steel ball. The flow rate scale on the flowmeter is properly read at the bottom of the ball.

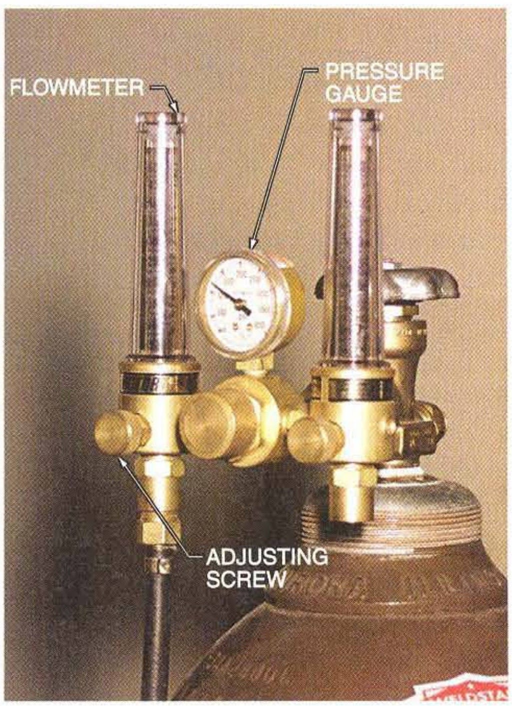


Figure 16-15. *A pressure regulator and flowmeter control the flow of shielding gas to the torch.*

Straight helium is less commonly used as a shielding gas because of its higher cost compared to argon. Establishing an arc with helium is also more difficult than with argon. Helium produces deeper weld penetration, but is lighter than air, requiring more gas to be used for adequate shielding. When welding metal that requires a higher heat input, a mixture of argon and helium may be used. Different percentages of argon and helium are used to obtain required penetration at the lowest cost.

When welding austenitic stainless steel using GTAW, hydrogen can be added to the shielding gas to reduce oxide formation. Nitrogen can be added to the shielding gas to increase mechanical properties and reduce pitting in super-austenitic and duplex stainless steels.

GTAW FILLER METALS

Normally, filler metal is not necessary on light-gauge metals. Occasionally, filler metal is added on thin metals when it is essential to reinforce the joint. When using the GTAW process for thick metals, filler metal is required. For joints where additional weld metal is needed, filler metal is fed into the weld pool in a manner similar to welding with the oxyacetylene flame process, melting the wire with the weld pool, not with the heat of the arc.

Filler metal must be of the same composition as the base metal. Thus, triple deoxidized mild steel filler metal is used to weld low-carbon steel, aluminum filler metal is used for welding aluminum, copper filler metal is used for joining copper, and so on. Strips of the base metal can also be used as a filler metal, if necessary.

If filler metal is to be used, it must be of the same composition as the base metal.

Filler metals for GTAW are similar in classification to the filler metals used for GMAW. See Appendix. Copper-coated mild steel filler metals used for oxyacetylene welding are not recommended for GTAW since they tend to contaminate the tungsten electrode. GTAW filler metals contain deoxidizers that produce less spatter in the weld and a sound weld joint. In general, the diameter of the filler metal should be about the same as the thickness of the metal to be welded.

POINTS TO REMEMBER

1. A welding machine originally designed for use with SMAW must be derated to protect it from the effects of internal heating that occurs during GTAW. Derating is only necessary when using AC GTAW.
2. ACHF provides a combination of the penetrating qualities of DCEN and the cleaning action of DCEP.
3. In the GTAW process, DCEN is used for welding most ferrous metals because it produces deep penetration into the metal.
4. DCEP is rarely used in GTAW except in special aluminum and magnesium applications.
5. A water-cooled torch is recommended when using currents over 200 A. Ensure cooling water is flowing before welding.
6. Gas nozzles that are too small for the welding task may overheat, crack, or deteriorate rapidly.
7. The diameter of the electrode selected for a welding operation is determined by the required welding current.
8. Before starting to weld, ensure that the tungsten electrode has the proper stickout beyond the end of the gas nozzle.
9. The type and amount of shielding gas used is determined by current, type of weld, base metal, and welding conditions.
10. Argon is the most commonly used shielding gas, and is regulated by a flowmeter.
11. If filler metal is to be used, it must be of the same composition as the base metal.

QUESTIONS FOR STUDY AND DISCUSSION

1. In GTAW, what type of welding machines may be used?
2. Why should an AC welding machine be of the high-frequency type?
3. What polarity is commonly used in GTAW?
4. When DCEP or DCEN current is used in GTAW, what results can be expected with respect to heat distribution?
5. What determines whether an air-cooled or water-cooled torch is used?
6. What precaution(s) should be observed when using a water-cooled torch?
7. Why is it important to use the correct size gas nozzle?
8. What determines the size of the tungsten electrode to be used for welding?
9. What is the recommended shape of the tungsten electrode for DC and AC welding?
10. What is the function of a flowmeter in a gas regulator assembly?
11. When using filler metal, how should it be manipulated?
12. When is filler metal used in GTAW?

GTAW – Procedures 17

Gas Tungsten Arc Welding (GTAW)

GTAW can be performed in all positions and produces a minimum of weld spatter. Weld spatter is greatly reduced or eliminated because no metal passes through the arc. Since GTAW produces a smooth weld surface and little or no metal finishing is required, there can be a savings in production cost. In addition, there is less distortion of the metal near the weld. However, production cost savings may be offset by low productivity and training for the additional skills necessary to perform GTAW.

GTAW CONSIDERATIONS

GTAW procedures must consider the base metal, weld joint, weld type, and welding position. Adjustments required for GTAW operations include selecting current type and level, selecting the tungsten electrode, adjusting cooling-water flow, selecting the shielding gas, adjusting shielding gas flow rate, and adjusting electrode extension.

GTAW can be applied by four basic processes: manual, semiautomatic, mechanized, and automatic. In the manual process, the operation is done by hand. GTAW, similar to OFW, can be performed in either forehand or backhand direction. In the semiautomatic process, the operator controls the speed and direction of travel, while the filler metal is automatically fed into the weld pool.

AWS A5.12/A5.12M, Specification for Tungsten and Tungsten Alloy Electrodes for Arc Welding and Cutting, *specifies the tungsten electrodes that may be used with GTAW. Commonly used tungsten electrodes are 1% or 2% thoriated electrodes. Thorium oxide enhances electron emission and provides a higher current-carrying capacity to the electrode.*

In the mechanized process, the filler metal feed, weld size, weld length, rate of travel, and starting and stopping are controlled by equipment under the observation and control of the welding operator. The automatic process performs all welding operations without constant observation and adjustment of the controls by an operator.

In GTAW welding, a shield of inert gas displaces air from the welding area to prevent oxidation of the filler metal, weld pool, and surrounding HAZ. When GTAW is properly performed, a smooth appearance is produced. Since the shielding gas around the arc is transparent, a welder can clearly observe the weld as it is being made. Additionally, the completed weld is clean and free of the defects often encountered in SMAW.

GTAW can be used for joining many metals and alloys in various thicknesses and for various types of joints.

Joint Preparation

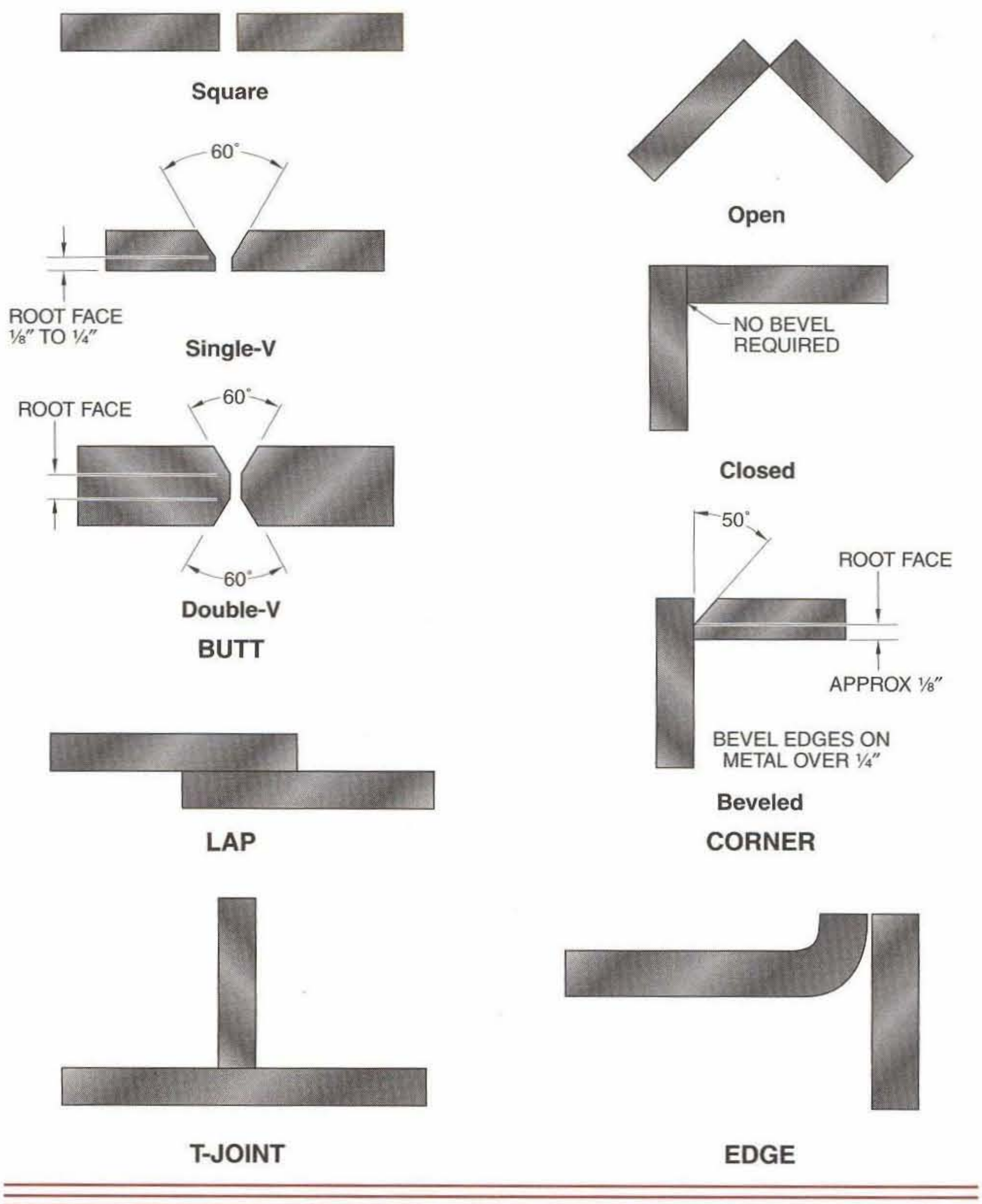
Regardless of the type of joint used, proper cleaning of the metal is essential. All oxidation, scale, oil, grease, dirt, and other foreign matter must be removed by physical or chemical means since there are no fluxing

agents as with SMAW to eliminate contaminants. Ideal joint preparation is obtained using cutting tools such as a lathe for round or cylindrical joints or a milling machine for longitudinal preparations. Problems that arise during GTAW are the result of using improper joint preparation methods. Many of these problems are the direct result of improper grinding of the metal.

Grinding wheels designed for specific metal types should be used to ensure proper metal preparation prior to welding. Micro-sized abrasive particles can permeate soft metals such as aluminum, and unless removed, result in excessive porosity. Grinding wheels must be thoroughly cleaned before each use. Joint designs used with GTAW include the butt joint, lap joint, T-joint, corner joint, and edge joint. See Figure 17-1.

Figure 17-1. *Joint designs used with GTAW include the butt joint, lap joint, T-joint, corner joint, and edge joint.*

GTAW Joint Designs
Figure 17-1



Butt Joints. For thin metals, the square butt joint is the easiest to prepare and can be welded with or without filler metal. If the weld is to be made without filler metal, extreme care must be taken to prevent melt-through.

To ensure complete joint penetration, the single-V butt joint is used on metal ranging in thickness from 3/8″ to 1/2″. The groove angle of the joint root should be approximately 60°, with a root face of about 1/8″ to 1/4″.

When the thickness of the metal exceeds 1/2″ and the joint design is such that the weld can be made on both sides, a double-V butt joint is used. With a double-V butt joint there is greater assurance of complete penetration of the weld.

Lap Joints. The only special requirement for making a good lap weld is to have the pieces in close contact along the entire length of the joint. The weld can be made with or without filler metal. As a rule, a lap joint is not recommended for material more than 1/4″ thick

T-Joints. Filler metal must be used to weld T-joints regardless of the thickness of the metal. Generally, the weld should be made on both sides of the T-joint. The number of passes required depends on the thickness of the metal and the size of the weld to be made.

Corner Joints. When welding a corner joint on thin metals up to 1/8″ thick, no filler metal is required. With thick metals, filler metal should be used. If the metal exceeds 1/4″, one edge of the joint should be beveled. The number of passes required for a corner joint depends on the size of the groove angle and the thickness of the metal.

Edge Joints. An edge joint is suitable only on very light metal. No filler metal is needed to weld an edge joint. Edge joints are used to join parallel or nearly parallel workpieces.

Weld Backing

Many welding jobs require the use of some suitable backing. On light-gauge metals, backing bars are used to prevent melt-through and protect the underside of the weld from atmospheric contamination. On thick metal, backing bars draw some of the heat generated by the intense arc away from the weld.

When welding light-gauge metals, backing bars can be used to prevent melt-through.

The type of metal used as a backing bar depends on the metal to be welded. Copper bars are suitable for stainless steel. When welding aluminum or magnesium, steel or stainless steel backing bars are needed. A backing bar should be positioned so it does not touch the weld zone. See Figure 17-2.

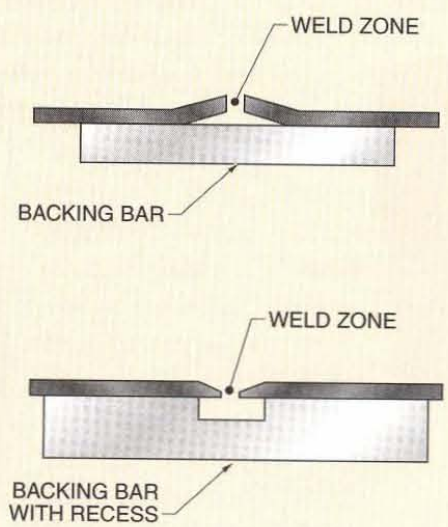


Figure 17-2. *A backing bar should be positioned so that it does not touch the weld zone.*

Many weld backings are consumed into the weld. Weld backing should be composed of the same material as the base metal.

When welding using the GTAW process, copper is commonly used as a backing material because it does not fuse to thin metals. Copper also provides fast cooling, which helps to control heat input.

GTAW PROCEDURES

The GTAW procedure is similar to the OFW procedure. The torch is manipulated to distribute the heat evenly in the weld area. Filler metal, if required, is added to the weld pool with an in-and-out motion. The travel angle used depends on the size and type of metal welded. When welding with ACHF current, the electrode must not touch the weld pool as the electrode could become contaminated. Before starting to weld with GTAW, follow the procedure:

1. Check all electrical circuit connections to make sure they are tight.
2. Check for the proper electrode diameter and gas nozzle size. (Follow manufacturer recommendations.)
3. Adjust for the proper electrode extension. Stickout of the electrode should be 1/8″ to 3/16″ beyond the end of the gas nozzle for a butt joint, 1/4″ to 3/8″ for a T-joint, and 1/8″ for a corner joint. See Figure 17-3.
4. Check the electrode to be certain that it is firmly held in the collet. If the electrode is loose, tighten the collet holder or gas nozzle. Do not overtighten as overtightening can strip the threads.
5. Set the welding machine for the correct current. See Appendix.
6. If a water-cooled torch is to be used, turn the water ON.
7. Set the inert gas to the correct flow. Set the postflow timer.

When using a water-cooled torch, ensure that the water is ON before welding.

Electrode Extension and Stickout
Figure 17-3

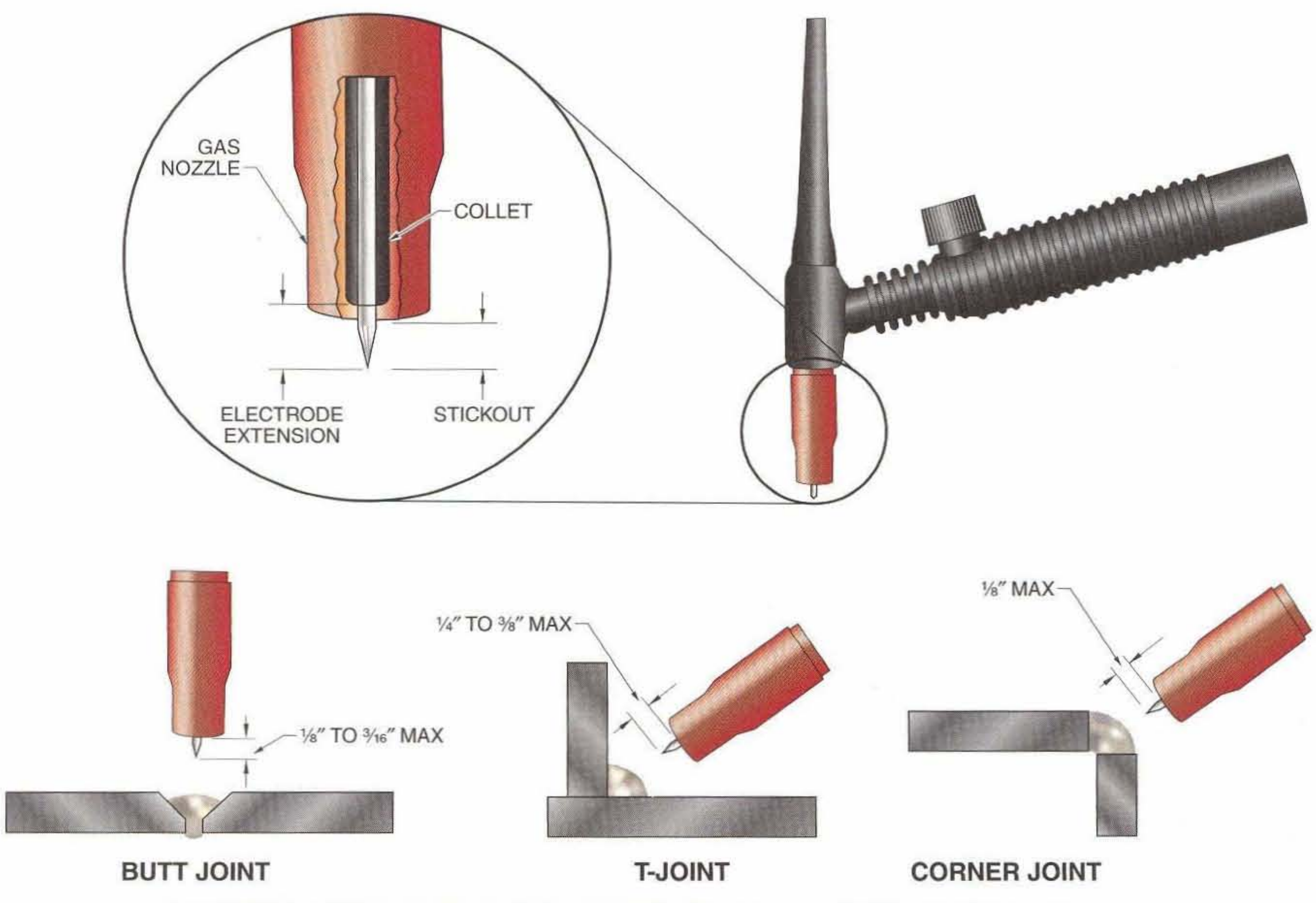


Figure 17-3. *Adjust the electrode extension to ensure the proper stickout for the particular joint being welded.*

Starting the Arc

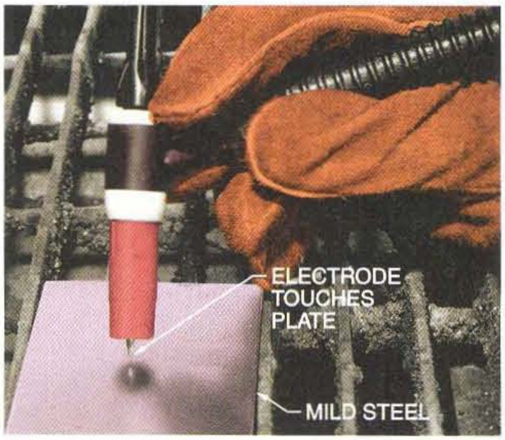
To start an arc, set the welding current and hold the torch in a horizontal position about 2″ above the workpiece. When using DC current, lower the torch until the electrode touches the workpiece. Once the arc is started, withdraw the electrode so it is about ⅛″ above the workpiece. See Figure 17-4.

When using ACHF, angle the torch so the end of the electrode is ⅛″ above the workpiece. The high-frequency current will jump the gap between the electrode and the workpiece, establishing the arc. The electrode should not touch the workpiece to start the arc. Rapidly make the downward motion to begin welding to provide the maximum amount of gas protection to the weld zone.

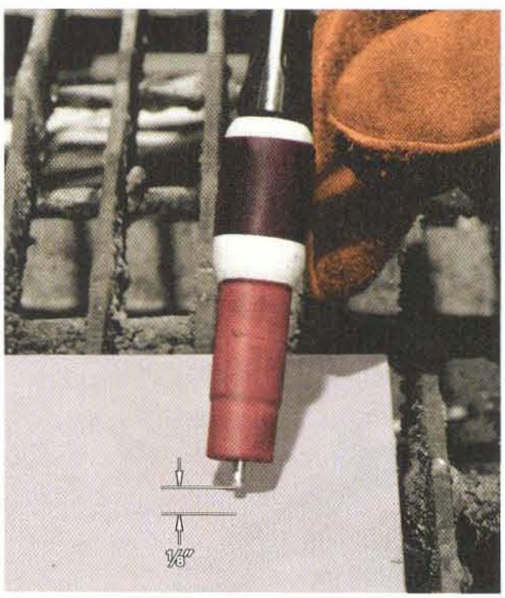
Many DC welding machines have a high-frequency start feature. If so, strike the arc in the manner described for ACHF.

To stop the arc during welding, swing the electrode back to the horizontal position without touching the weld area. Some machines are equipped with a foot pedal to permit a gradual decrease of current for filling the crater completely and preventing crater cracks.

Starting the Arc (GTAW)
Figure 17-4



When starting an arc using DC current, the electrode is lowered until it touches the plate.



When starting the arc using AC, angle torch so electrode is ⅛″ above workpiece. Current will jump gap and establish an arc.

Figure 17-4. *When starting an arc, the proper arc length must be maintained to produce a quality weld.*

Welding Butt Joints. Preheat the starting point of the weld by moving the torch in small circles to develop a weld pool. As soon as the weld pool becomes fluid, move the torch slowly and steadily along the joint to deposit a uniform bead. See Figure 17-5. To add filler metal to a butt joint, follow the procedure:

1. With the arc at the rear of the weld pool, add filler metal to the leading edge of the weld pool while maintaining a 15° push angle between the filler metal and the surface of the work.
2. Remove the filler metal from the weld area.
3. Advance the torch to the leading edge of the weld pool.

Repeat this sequence for the entire length of the seam.

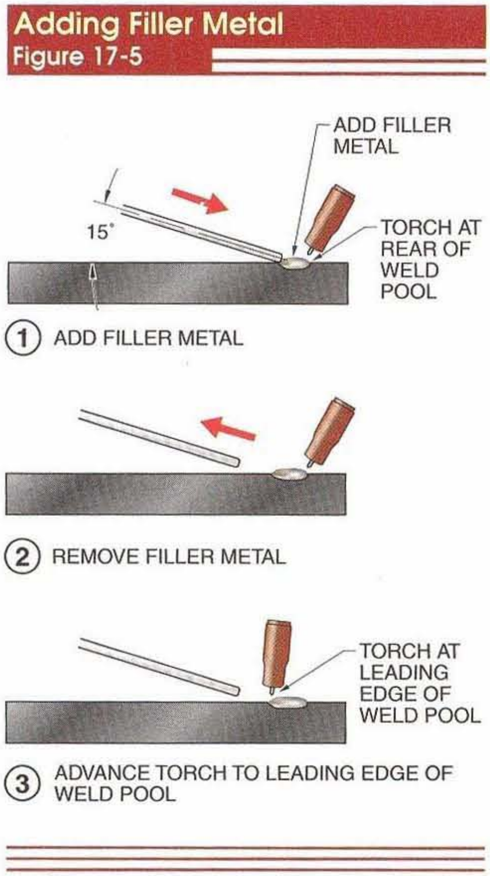
Welding Lap Joints or T-Joints. To weld a lap joint, the workpieces must be in close contact. On metal ¼″ thick or less, the weld can be made with or without filler metal. Lap joints are typically not used for metal more than ¼″ thick. Filler metal is required when welding T-joints, regardless of the thickness of the metal.

To begin welding, form a weld pool on the bottom workpiece. After the weld pool is formed, shorten the arc to

⚠ CAUTION

If using a water-cooled torch, do not allow it to contact the workpiece when the current is ON. Hot welding gases may cause the arc to jump from the electrode to the gas nozzle instead of to the workpiece.

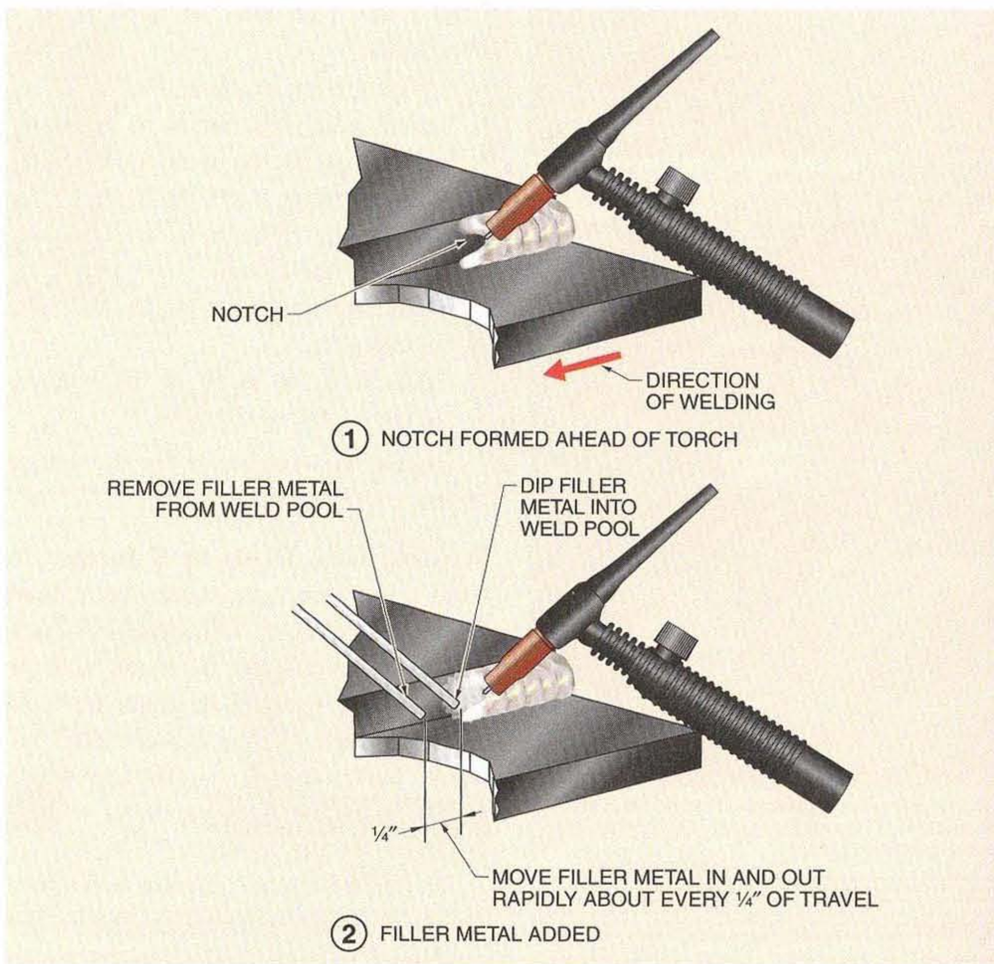
Figure 17-5. *Filler metal is added to the leading edge of the weld pool.*



about 1/16″, then rotate the torch directly over the joint until the workpieces are joined. After welding is started, no further torch rotation is necessary. Move the torch along the joint with the end of the filler metal just above the edge of the top workpiece.

When welding a lap joint, the weld pool forms a V shape. Inside the weld pool a notch is formed. The speed at which this notch progresses determines how fast the torch should be moved. Do not advance the torch ahead of the notch. The notch must be completely filled for the entire length of the joint; otherwise, incomplete fusion and penetration of the weld results. See Figure 17-6. Dip the end of the filler metal in and out of the weld pool about every 1/4″ of travel. Avoid depositing filler metal on cold, unmolten base metal. Adding a consistent amount of filler metal ensures that a uniform bead is produced.

Figure 17-6. *Advance the torch so that the notch in the weld bead continues to form ahead of the torch.*



Horizontal Welding Procedure

For horizontal GTAW, start the arc about ½″ from the edge of the joint. Once the arc is started, move the torch to the edge of the joint and begin welding. Hold the torch at a work angle of 15° and a travel angle of 15°. Dip the filler metal into the front of the weld pool and on the high side of the crater as the torch is advanced along the joint to help prevent undercutting. See Figure 17-7.

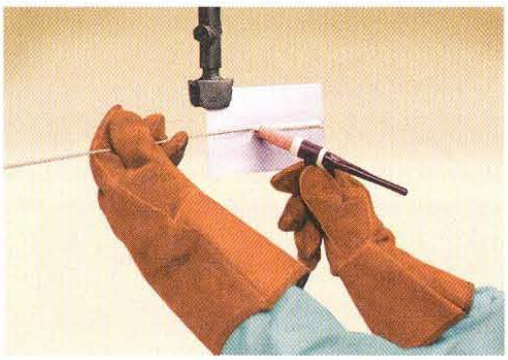


Figure 17-7. *Dip the filler metal into the high side at the front of the weld pool when welding a horizontal butt joint.*

While the filler metal is dipped into the weld pool, withdraw the torch slightly to allow the molten metal to solidify, which prevents the weld pool from sagging. Arc length should be approximately the same size as the filler metal diameter.

Vertical Welding Procedure

Vertical GTAW on thin metal is usually performed downhill to achieve an adequate weld without melt-through. When filler metal is used, it should be added from the bottom, or leading, edge of the weld pool. On thick metals, uphill welding is preferred since deeper penetration can be achieved. Uphill welding generally requires filler metal. The proper work angle and travel angle must be maintained for both downhill and uphill welding. See Figure 17-8.

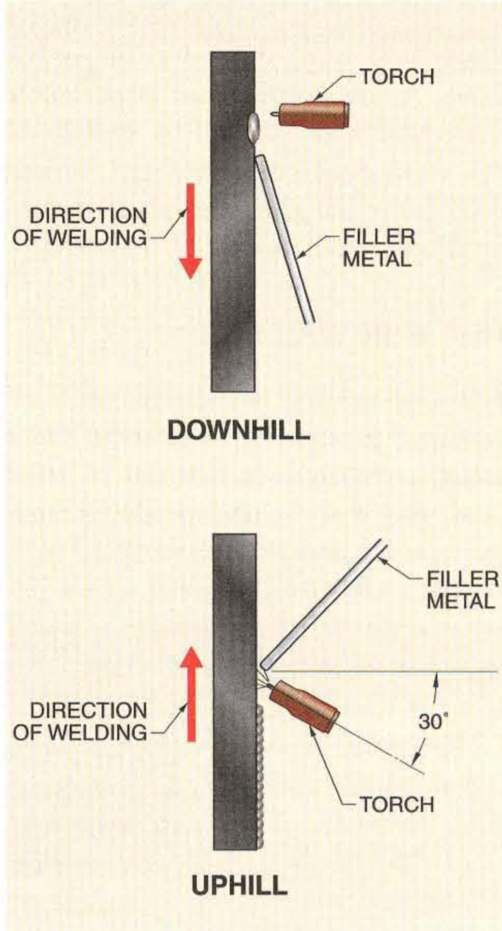


Figure 17-8. *The proper angles must be maintained when performing downhill and uphill welding.*

Using downhill GTAW on thin metal produces an adequate weld with no melt-through.

Overhead Welding Procedure

When welding with GTAW in overhead position, the current should be reduced 5% to 10% from what is normally used for flat position. A reduced current provides better control of the weld pool. Both the torch and filler metal should be held similar to flat position welding. A work angle of 15° and a travel angle of 15° to 20° should be maintained. See Figure 17-9.

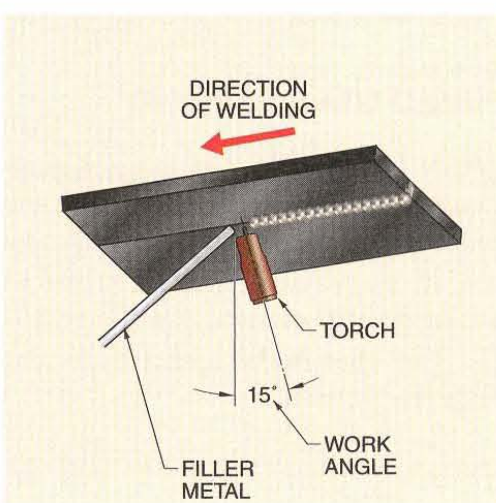


Figure 17-9. *The travel angle and work angle of the torch in overhead position is similar to flat position.*

When using GTAW in overhead position, reduce the current 5% to 10% from what is used for flat position.

Dip the filler metal in and out of the weld pool as in other welding positions. A small weld bead is advisable since it is less affected by gravity. If the weld pool gets too large, it will drop out of the joint and complete penetration cannot occur.

HOT WIRE WELDING

Hot wire welding is a gas tungsten arc welding process in which the filler metal is preheated as it enters the weld pool. Hot wire welding produces quality welds at about the same speed as is possible with GMAW. In hot wire welding systems, the filler metal is automatically fed from a wire feeder that runs to a hot-wire torch mounted behind the GTAW torch. A *wire feeder* is a welding machine accessory that holds a filler metal spool and allows it to be fed to the hot-wire torch as welding progresses. Filler metal is melted by an AC current that passes from an AC welding machine through the filler metal. The welding machine is regulated so the filler metal reaches its melting point as it enters the weld pool.

By attaching the hot-wire torch behind the GTAW welding torch, the operator is given an unobstructed view of the weld. By preheating the filler metal, weld porosity is eliminated. Welds are made with greater quality and speed.

Hot wire welding is a rapid and efficient welding process in many fabrication situations.

PULSED GTAW (GTAW-P)

Pulsed GTAW (GTAW-P) is a gas tungsten welding arc process in which the welding current is pulsed. The high and low level pulsating current produces overlapping spot welds. See Figure 17-10. The spot welds are formed by high-level current.

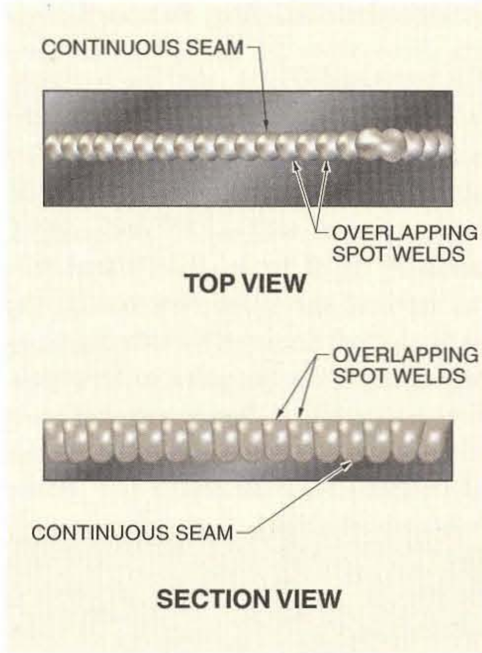


Figure 17-10. *The pulsed GTAW process produces overlapping spot welds that form a continuous seam.*

When the current switches to a low level, the welds are allowed to cool and partially solidify between deposition of each spot weld. The welding controls are set so the spot welds overlap to produce a continuous weld.

Pulsed GTAW can be manual or automatic and can be used with or without filler metal. The process can be used for welding very thin metals where critical control of metallurgical factors is necessary. A pulsed current permits more tolerance of edge misalignment, greater variations in backing bar use and fixturing, better root penetration, and less distortion.

With other welding techniques, a change in current or travel speed must be made when changing positions around curved edges to ensure uniform weld appearance. Pulsed GTAW is more flexible when used in different welding positions and, when welding curved seams or pipes, allows continuous welding without having to vary travel speed, voltage, or current.

POINTS TO REMEMBER

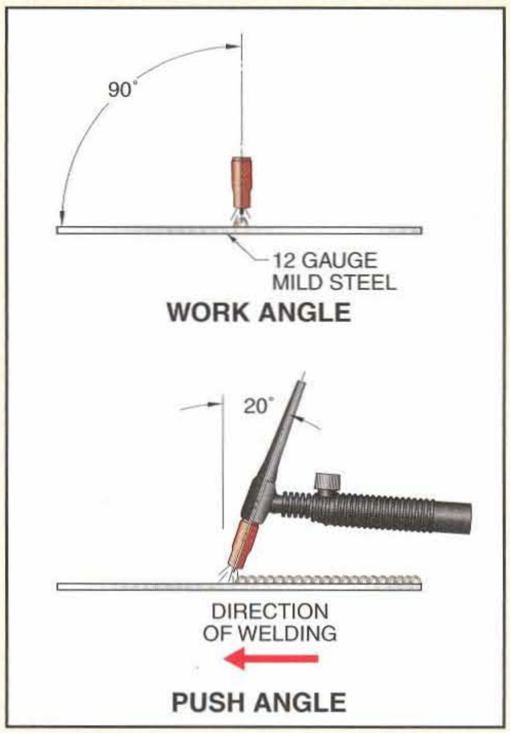
1. GTAW can be used for joining many metals and alloys in various thicknesses and types of joints.
2. When welding light-gauge metals, backing bars can be used to prevent melt-through.
3. When using a water-cooled torch, ensure that the water is ON before welding.
4. Using downhill GTAW on thin metal produces an adequate weld with no melt-through.
5. Dip the filler metal into the high side at the front edge of the weld pool when welding a horizontal butt joint.
6. When using GTAW in overhead position, reduce the current 5% to 10% from what is used for flat position.

Exercises

Depositing Beads on Mild Steel in Flat Position

exercise 1

1. Obtain a 3/32″, 1% thoriated tungsten electrode and prepare a pointed tip.
2. Insert the electrode in the torch and adjust the stickout 1/8″ to 3/16″ beyond the end of the gas nozzle.
3. Set the welding machine output to DCEN. If the welding machine has a high-frequency start feature, set the high frequency for start only. Weld current remote should be OFF and contactor control should be ON.
4. Set the shielding gas (argon) at 20 cubic feet per minute (cfm) with a postflow time of 15 sec.
5. Set the current at 50 A to 60 A.
6. Obtain a piece of 12 gauge mild steel, 4″ wide and 6″ long.
7. Position the workpiece in flat position.
8. Start current flow by pushing the foot pedal or turning the switch at the torch.

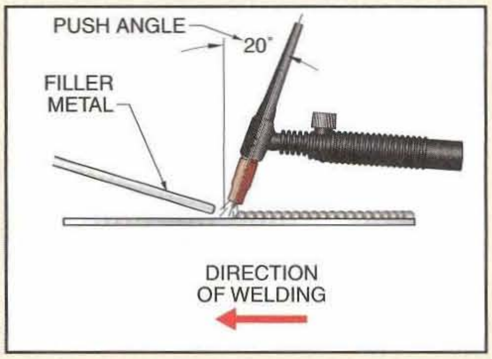


9. Position the torch at a 45° work angle with the electrode 1/8″ from the workpiece.
10. Once the arc is started, raise the torch to a 90° work angle and a 20° push angle.
11. Maintain the arc size with a weld pool approximately 1/8″ wide. Form a consistent bead across the workpiece.
12. Deposit a series of straight, consistent beads on the workpiece approximately 3/8″ apart.

Depositing Beads with Filler Metal on Mild Steel in Flat Position

exercise 2

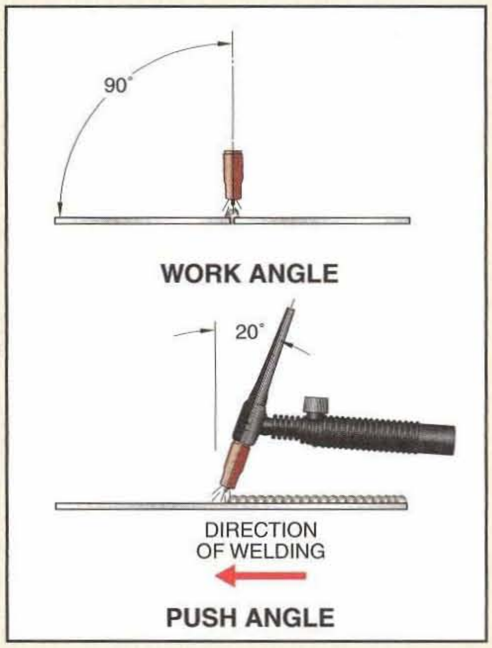
1. Complete equipment setup and adjustment as in Exercise 1.
2. Obtain a piece of 12 gauge mild steel, 4″ wide and 6″ long.
3. Position the workpiece in flat position.
4. Obtain the recommended filler metal for mild steel.
5. Position the torch at a 45° work angle with the electrode ⅛″ from the workpiece.
6. Once the arc is started, establish a weld pool and raise the torch to a 90° work angle and a 20° push angle. Using an in-and-out motion, dip the filler metal into the leading edge of the weld pool. Do not touch the filler metal to the tungsten electrode.
7. Use a small circular motion with the torch. Form a consistent bead, approximately 3⁄16″ wide, and maintain across the workpiece.
8. Deposit a series of straight, consistent beads approximately ⅜″ apart.



Welding a Butt Joint on Mild Steel in Flat Position...

exercise 3

1. Complete equipment setup and adjustment as in Exercise 1.
2. Obtain two pieces of 12 gauge mild steel, 1½″ wide and 6″ long.
3. Form a butt joint with no root opening, and tack together.
4. Position the workpiece so the weld joint is in flat position.
5. Obtain the recommended filler metal for mild steel.
6. Position the torch at a 45° work angle with the electrode ⅛″ from the workpiece.



...Welding a Butt Joint on Mild Steel in Flat Position

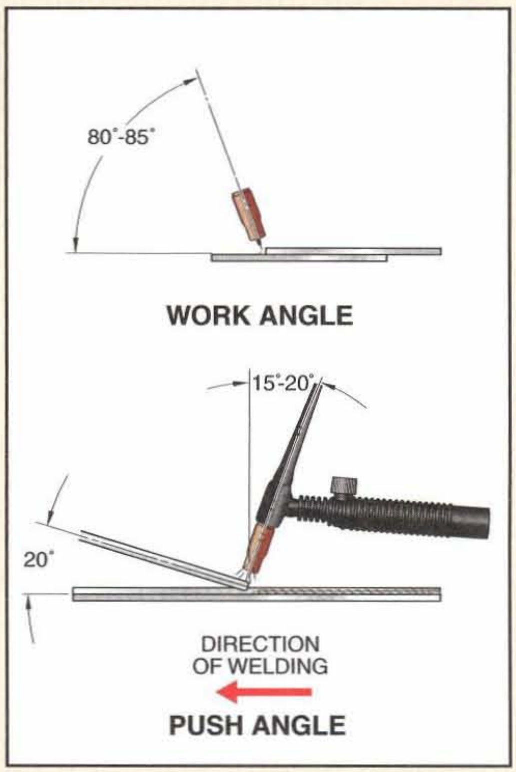
exercise 3

7. Once the arc is started, establish a weld pool and raise the torch to a 90° work angle and a 20° push angle. Using an in-and-out motion, dip the filler metal into the leading edge of the weld pool. Do not touch the filler metal to the tungsten electrode.
8. Use a small circular motion with the torch. Form a consistent bead, approximately 3/16″ wide, and deposit the bead across the workpiece, using the weld joint as the center of the weld.
9. The resulting weld should have complete penetration with a 3/16″ bead width.

Welding a Lap Joint on Mild Steel in Horizontal Position

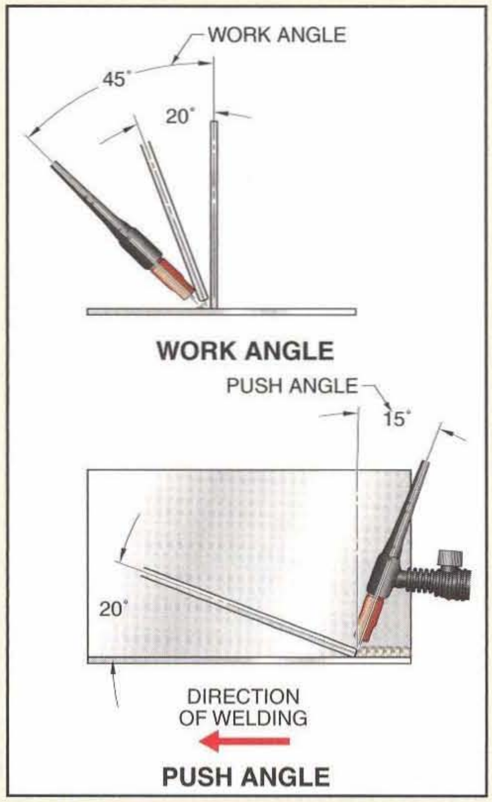
exercise 4

1. Complete equipment setup and adjustment as in Exercise 1.
2. Obtain two pieces of 12 gauge mild steel, 1½″ wide and 6″ long.
3. Form a lap joint and tack together.
4. Position the workpiece so the weld joint is in horizontal position.
5. Obtain the recommended filler metal for mild steel.
6. Hold the torch at an 80° to 85° work angle and a 15° to 20° push angle. Position the filler metal at a 20° angle.
7. Melt the top edge of the workpiece and add filler metal using an in-and-out motion to the leading edge of the weld pool.
8. Maintain a consistent bead across the workpiece.



Welding a T-Joint on Mild Steel in Horizontal Position

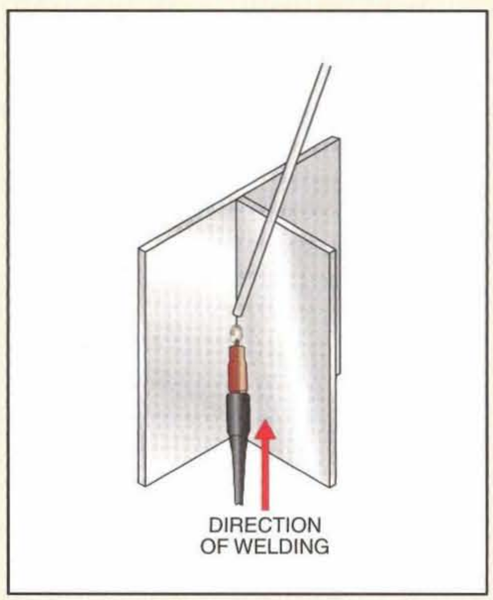
exercise 5



1. Complete equipment setup and adjustment as in Exercise 1.
2. Obtain two pieces of 12 gauge mild steel, 2″ wide and 6″ long.
3. Form a T-joint with the pieces at a 90° angle and tack together.
4. Position the workpiece so the weld joint is in horizontal position.
5. Obtain the recommended filler metal for mild steel.
6. Hold the torch at a 45° work angle and a 15° push angle. Position the filler metal at a 20° angle from the bottom plate.
7. Establish a weld pool. Weave the torch slightly and, using an in-and-out motion, add filler metal to the leading edge of the weld pool.
8. Avoid excessive heat buildup on the vertical workpiece.

Welding a T-Joint on Mild Steel in Vertical Position

exercise 6



1. Complete equipment setup and adjustment as in Exercise 1.
2. Obtain two pieces of 12 gauge mild steel, 2″ wide and 6″ long.
3. Form a T-joint with the pieces at a 90° angle and tack together.
4. Position the workpiece so the weld joint is in vertical position.
5. Obtain the recommended filler metal for mild steel.
6. Weld uphill. Start at the bottom of the joint. Hold the torch at a 45° work angle and a 20° push angle. Position the filler metal at a 20° angle, centered on the joint. Use an in-and-out motion and add filler metal to the leading edge of the weld pool.

Depositing Beads on Aluminum in Flat Position

exercise 7

1. Obtain a 3/32″, pure tungsten electrode and insert the electrode in the torch. Adjust the stickout 1/8″ to 3/16″ beyond the end of the gas nozzle and prepare a spherical tip. To shape the tip, set the welding machine to DCEP. Position the torch at a 90° angle and strike an arc on a piece of copper. A small ball will form on the end of the electrode.
2. Set the welding machine output to AC. High frequency should be set for continuous. Weld current remote and contactor control should be ON.
3. Set the shielding gas (argon) to 20 cfm with a postflow time of 15 sec.
4. Set the current at 140 A to 150 A.
5. Obtain a piece of 1/8″ aluminum, 4″ wide and 6″ long.
6. Clean the aluminum with a clean stainless steel wire brush.
7. Position the workpiece in flat position.
8. Start the welding arc, using the foot control to vary the current.
9. Hold the torch at a 90° work angle and a 20° push angle.
10. Melt the aluminum to form a 1/4″ wide bead weld pool. Use an in-and-out motion and add filler metal to the leading edge of the weld pool. A slight weaving motion can be used.
11. Fill the crater at the end of the weld by reducing current with the foot control and continuing to add filler metal.
12. Deposit a series of straight, consistent beads on the workpiece approximately 3/8″ apart.

Welding Joints on Aluminum in Flat Position

exercise 8

1. Complete equipment setup and adjustment as in Exercise 7.
2. Obtain six pieces of 1/8″ aluminum.
3. Position the aluminum in flat position.
4. Use the procedures for welding mild steel to complete a butt joint, a lap joint, and a T-joint on aluminum.

QUESTIONS FOR STUDY AND DISCUSSION

1. What does GTAW stand for?
2. What are some of the advantages of GTAW compared to other welding processes?
3. How is the arc started and stopped in GTAW?
4. What is the proper torch angle for welding a butt joint?
5. What is hot wire welding?
6. How are welds produced by the pulsed GTAW process?
7. What kind of metal(s) can be welded with the GTAW process?
8. Why is joint cleanliness more important with GTAW compared to SMAW?

GTAW – Applications 18

Gas Tungsten Arc Welding (GTAW)

GTAW is used where accurate control of weld penetration and weld purity are critical, and deposited weld metal must be free of spatter, allowing metal finishing without cleaning or extensive preparation. Common applications of welding using GTAW are on aluminum, stainless steel, copper and copper alloys, magnesium, carbon steels, and other metals that cannot be welded satisfactorily using other welding processes.

The GTAW welding technique for metals such as aluminum, stainless steel, copper, magnesium, and carbon steel is virtually the same for each type of metal. In general, these metals can be welded with GTAW more easily and with better results than by OAW or SMAW. Filler metal used for oxyacetylene welding is not suitable for use with GTAW.

GTAW is commonly used for joining metals in the aerospace and aircraft industries. The low heat input of GTAW permits welding on very thin metal with minimal distortion and/or alteration of base metal properties. GTAW is also used when welding pressure vessels and critical piping systems, such as systems in nuclear power plants, because of its weld penetration and purity.

ALUMINUM

Aluminum is a nonferrous metal, which means that it contains no iron. Many types of pure and alloyed aluminums are available and each has specific properties for specific end uses. With advancements and improvements in welding equipment, welding of aluminum has become a more common joining process used in industry.

Nonheat-treatable wrought aluminum alloys in the 1000, 3000, and 5000 series are readily weldable. Heat-treatable alloys in the 2000, 6000, and 7000 series can be welded, but higher welding temperatures and welding speeds are required. Weld cracking in alloys can be eliminated by using filler metal that has a higher alloy content than that of the base metal.

Welding can be performed in any position; however, welding is easier and the quality of the completed weld is increased if welding is done in flat position. Copper backing bars should be used whenever possible to minimize distortion, especially on light-gauge metal ⅛″ thick or less. In most cases, the torch should be moved in a straight line without a weaving motion. Best results are obtained by using ACHF current with argon as a shielding gas. Welding parameters such as current, electrode diameter, argon flow rate, and filler metal diameter, should be set based on the thickness of the aluminum. See Figure 18-1.

To prevent moisture absorption, which can cause porosity in welds on aluminum, run an arc on a scrap of metal after a long shutdown (overnight) to clear condensation from the shielding gas lines.

When welding light-gauge metals, a copper backing bar is usually required.

GTAW—ALUMINUM								
Metal Thickness*	Joint Type	AC Current†			Electrode* Diameter	Argon Flow‡		Filler Metal Diameter*
		Flat	Horizontal & Vertical	Overhead		lpm	cfh	
1/16	Butt	60 – 80	60 – 80	60 – 80	3/32	7	15 – 20	3/32
	Lap	70 – 90	55 – 75	60 – 80	3/32	7	15 – 20	3/32
	Corner	60 – 80	60 – 80	60 – 80	3/32	7	15 – 20	3/32
	Fillet	70 – 90	70 – 90	70 – 90	3/32	7	15 – 20	3/32
1/8	Butt	125 – 145	115 – 135	120 – 140	1/8	8	17 – 20	1/8
	Lap	120 – 130	125 – 145	120 – 130	1/8	8	17 – 20	1/8
	Corner	125 – 145	115 – 135	120 – 130	1/8	8	17 – 20	1/8
	Fillet	120 – 130	115 – 135	120 – 130	1/8	8	17 – 20	1/8
3/16	Butt	160 – 180	160 – 180	160 – 170	5/32	10	20	5/32
	Lap	170 – 180	160 – 180	160 – 170	5/32	10	20	5/32
	Corner	160 – 180	160 – 180	160 – 170	5/32	10	20	5/32
	Fillet	170 – 180	160 – 180	160 – 170	5/32	10	20	5/32
1/4	Butt	220 – 240	210 – 230	200 – 220	3/16	12	25	3/16
	Lap	230 – 250	210 – 230	200 – 220	3/16	12	25	3/16
	Corner	230 – 250	210 – 230	200 – 220	3/16	12	25	3/16
	Fillet	230 – 250	210 – 230	200 – 220	3/16	12	25	3/16

* in in.
† amps
‡ 20 psi [in inches per minute (ipm) or cubic feet per hour (cfh)]

Figure 18-1. *Welding parameters should be set based on aluminum thickness.*

STAINLESS STEEL

Stainless steels, especially those in the 300 series, are easy to weld with GTAW. Either DCEN or ACHF can be used. GTAW is particularly adaptable for welding light-gauge stainless steel and high-pressure stainless steel piping.

The procedure for welding all types of stainless steels is the same. Filler metals for welding stainless steels are alloyed to prevent cracking problems. When welding without filler metals, care must be taken to prevent cracking. The danger of cracking is reduced if the metal is preheated to a temperature of 300°F (148°C) to 500°F (260°C). Welding parameters such as proper current, electrode diameter, argon flow rate, and filler metal diameter, should be set based on the thickness of the stainless steel. See Figure 18-2.

Ensure that there is good ventilation when welding. Fumes from metals are highly toxic.

COPPER AND COPPER ALLOY

Deoxidized copper is the type of copper most widely used for GTAW. Copper alloys such as brass and bronze and copper alloys of nickel, aluminum, silicon, and beryllium are readily welded with GTAW. DCEN is generally used for welding these metals. However, ACHF or DCEP is often recommended for beryllium copper or for copper alloys less than .040″ thick. Metal more than 1/4″ thick should be preheated to approximately 300°F (148°C) to 500°F (260°C) prior to welding. A forehand welding technique usually produces the best results. Welding parameters such as proper current, electrode diameter, argon flow rate, and filler metal diameter, should be set based on the thickness of the copper or copper alloy. See Figure 18-3 and Figure 18-4.

A high-velocity ventilating system should be used when welding copper or copper alloys. The fumes from these metals are toxic.

MAGNESIUM

The welding characteristics of magnesium are comparable to those of aluminum. Both have high heat conductivity, low melting point, high thermal expansion, and rapid oxidization. With GTAW, several current variations are possible. Using DCEP with helium as a shielding gas produces wide weld deposits, higher heat, a large HAZ, and shallow penetration.

GTAW—STAINLESS STEEL								
Metal Thickness*	Joint Type	AC Current†			Electrode* Diameter	Argon Flow‡		Filler Metal Diameter*
		Flat	Horizontal & Vertical	Overhead		lpm	cfh	
1/16	Butt	80 – 100	70 – 90	70 – 90	1/16	5	15	1/16
	Lap	100 – 120	80 – 100	80 – 100	1/16	5	15	1/16
	Corner	80 – 100	70 – 90	70 – 90	1/16	5	15	1/16
	Fillet	90 – 110	80 – 100	80 – 100	1/16	5	15	1/16
3/32	Butt	100 – 120	90 – 110	90 – 110	1/16	5	15	1/16
	Lap	110 – 130	100 – 120	100 – 120	1/16	5	15	1/16
	Corner	100 – 120	90 – 110	90 – 110	1/16	5	15	1/16
	Fillet	110 – 130	100 – 120	100 – 120	1/16	5	15	1/16
1/8	Butt	120 – 140	110 – 130	105 – 125	3/32	5	15	3/32
	Lap	130 – 150	120 – 140	120 – 140	3/32	5	15	3/32
	Corner	120 – 140	110 – 130	115 – 135	3/32	5	15	3/32
	Fillet	130 – 150	115 – 135	120 – 140	3/32	5	15	3/32
3/16	Butt	200 – 250	150 – 200	150 – 200	3/32	6	20	1/8
	Lap	225 – 275	175 – 225	175 – 225	3/32	6	20	1/8
	Corner	200 – 250	150 – 200	150 – 200	3/32	6	20	1/8
	Fillet	225 – 275	175 – 225	175 – 225	3/32	6	20	1/8
1/4	Butt	275 – 350	200 – 250	200 – 250	1/8	6	20	3/16
	Lap	300 – 375	225 – 275	225 – 275	1/8	6	20	3/16
	Corner	275 – 350	200 – 250	200 – 250	1/8	6	20	3/16
	Fillet	300 – 375	225 – 275	225 – 275	1/8	6	20	3/16

* in in.
† amps
‡ 20 psi [in inches per minute (ipm) or cubic feet per hour (cfh)]

Figure 18-2. *Welding parameters should be set based on stainless steel thickness.*

GTAW—DEOXIDIZED COPPER						
Metal Thickness*	Joint Type	DCEN†	Electrode* Diameter	Argon Flow‡		Filler Metal Diameter*
		Flat Position		lpm	cfh	
1/16	Butt	110 – 140	1/16	7	15	1/16
	Lap	130 – 150	1/16	7	15	1/16
	Corner	110 – 140	1/16	7	15	1/16
	Fillet	130 – 150	1/16	7	15	1/16
1/8	Butt	175 – 225	3/32	7	15	3/32
	Lap	200 – 250	3/32	7	15	3/32
	Corner	175 – 225	3/32	7	15	3/32
	Fillet	200 – 250	3/32	7	15	3/32
3/16	Butt	250 – 300	1/8	7	15	1/8
	Lap	275 – 325	1/8	7	15	1/8
	Corner	250 – 300	1/8	7	15	1/8
	Fillet	275 – 325	1/8	7	15	1/8
1/4	Butt	300 – 350	1/8	7	15	1/8
	Lap	325 – 375	1/8	7	15	1/8
	Corner	300 – 350	1/8	7	15	1/8
	Fillet	325 – 375	1/8	7	15	1/8

* in in.
† amps
‡ 20 psi [in inches per minute (ipm) or cubic feet per hour (cfh)]

Figure 18-3. *Welding parameters should be set based on copper thickness.*

GTAW—COPPER ALLOYS								
Metal Thickness*	Joint Type	DCEN†			Electrode* Diameter	Argon Flow‡		Filler Metal Diameter*
		Flat	Horizontal & Vertical	Overhead		lpm	cfh	
1/16	Butt	100 – 120	90 – 110	90 – 110	1/16	6	13	1/16
	Lap	110 – 130	100 – 120	100 – 120	1/16	6	13	1/16
	Corner	100 – 130	90 – 110	90 – 110	1/16	6	13	1/16
	Fillet	110 – 130	100 – 120	100 – 120	1/16	6	13	1/16
1/8	Butt	130 – 150	120 – 140	120 – 140	1/16	7	15	3/32
	Lap	140 – 160	130 – 150	130 – 150	1/16, 3/32	7	15	3/32
	Corner	130 – 150	120 – 140	120 – 140	1/16	7	15	3/32
	Fillet	140 – 160	130 – 150	130 – 150	1/16, 3/32	7	15	3/32
3/16	Butt	150 – 200	–	–	3/32	8	17	1/8
	Lap	175 – 225	–	–	3/32	8	17	1/8
	Corner	150 – 200	–	–	3/32	8	17	1/8
	Fillet	175 – 225	–	–	3/32	8	17	1/8
1/4	Butt	150 – 200	–	–	3/32	9	19	1/8, 3/16
	Lap	250 – 300	–	–	1/8	9	19	1/8, 3/16
	Corner	175 – 225	–	–	3/32	9	19	1/8, 3/16
	Fillet	175 – 225	–	–	3/32	9	19	1/8, 3/16

* in in.
† amps
‡ 20 psi [in inches per minute (ipm) or cubic feet per hour (cfh)]

Figure 18-4. *Welding parameters should be set based on copper alloy thickness.*

Filler metal containing deoxidizers should be used when welding with GTAW to prevent porosity in the weld.

Medium- and high-carbon steels require preheat and postheating to avoid loss of toughness and ductility.

ACHF, used with helium, argon, or a mixture of shielding gases, can join metals from approximately .20″ to 1/4″ thick. Both DCEP and AC current provide excellent cleaning action of the base metal surface. Using DCEN with helium as a shielding gas produces a deep penetrating arc but no surface cleaning. DCEN with helium is used for mechanized butt welding of metal up to 1/4″ thick without beveling. Welding parameters such as proper current, electrode diameter, argon flow rate, and backing requirements, should be set based on the thickness of the magnesium. See Figure 18-5.

CARBON STEEL

Carbon steel can be welded using a variety of welding processes. GTAW can be used for welding low- and medium-carbon and low-alloy steels when greater protection of the weld from atmospheric contamination is required. GTAW is typically limited to metals less than 1/4″ thick. When GTAW is used on carbon steels without filler metal, there may be some pitting (porosity) in the weld. Porosity can be eliminated by lightly brushing the joint with a mixture of aluminum powder and methyl alcohol before welding. When filler metal is used, it should contain deoxidizers to prevent porosity.

Medium- and high-carbon steels are weldable, but preheat, special welding techniques, and postheating are required. Unless these precautions are taken, the welded area loses toughness and ductility.

GTAW is rarely used to weld high-carbon steels because the welding temperature required with GTAW tends to destroy the mechanical properties of the carbon steel. Common practice when repairing broken parts made with high-carbon steels is to use a brazing process where the heat is not sufficient to affect metallurgical structure. Welding parameters such as proper current, electrode diameter, argon flow rate, and backing requirements, should be set based on the thickness of the carbon steel. See Figure 18-6.

GTAW—MAGNESIUM							
Metal Thickness*	Joint Type	AC Current† Flat Position	Tungsten Electrode Diameter*	Argon Flow‡ lpm	Argon Flow‡ cfh	Welding Metal Diameter*	Remarks
.040	Butt	45	1/16	6	13	3/32	Backing bar
	Butt	25	1/16	6	13	3/32	No backing
	Fillet	45	1/16	6	13	3/32	
.064	Butt	60	1/16	6	13	3/32	Backing bar
	Butt, Corner	35	1/16	6	13	3/32	No backing
	Fillet	60	1/16	6	13	3/32	
.081	Butt	80	1/16	6	13	3/32	Backing bar
	Butt, Corner, Edge	50	1/16	6	13	3/32	No backing
	Fillet	80	1/16	6	13	3/32	
.102	Butt	100	3/32	9	19	1/8	Backing bar
	Butt, Corner, Edge	70	3/32	9	19	1/8	No backing
	Fillet	100	3/32	9	19	1/8	
.128	Butt	115	3/32	9	19	1/8	Backing bar
	Butt, Corner, Edge	85	3/32	9	19	1/8	No backing
	Fillet	115	3/32	9	19	1/8	
3/16	Butt	120	1/8	9	19	1/8	1 pass
	Butt	75	1/8	9	19	1/8	2 passes
1/4	Butt	130	1/8	9	19	3/16	1 pass
	Butt	85	1/8	9	19	3/16	2 passes

* in in.
† amps (non-derated current levels)
‡ 15 psi [in inches per minute (ipm) or cubic feet per hour (cfh)]

Figure 18-5. *Welding parameters should be set based on magnesium thickness.*

GTAW—CARBON STEEL				
Metal Thickness*	DCEN†	Argon Flow‡ lpm	Argon Flow‡ cfh	Filler Metal Diameter*
.035	100	4 – 5	8 – 10	1/16
.049	100 – 125	4 – 5	8 – 10	1/16
.060	125 – 140	4 – 5	8 – 10	1/16
.089	140 – 170	4 – 5	8 – 10	1/16

* in in.
† amps
‡ 20 psi [in inches per minute (ipm) or cubic feet per hour (cfh)]

Figure 18-6. *Welding parameters should be set based on carbon steel thickness.*

POINTS TO REMEMBER

1. When welding light-gauge metals, a copper backing bar is usually required.
2. Ensure that there is good ventilation when welding copper or copper alloys. Fumes of these metals are highly toxic.
3. Filler metal containing deoxidizers should be used when welding with GTAW to prevent porosity in the weld.
4. Medium- and high-carbon steels require preheat and postheating to avoid loss of toughness and ductility.

QUESTIONS FOR STUDY AND DISCUSSION

1. How can weld cracking in alloys be eliminated?
2. What preheat temperature should be used on stainless steel to reduce the danger of cracking?
3. What preheat temperature should be used on copper workpieces more than 1/4″ thick?
4. What are some of the properties of magnesium?
5. What are the benefits of DCEP and ACHF when welding magnesium?
6. What defect may occur when GTAW is used on carbon steels without filler metal?

19 GMAW–Equipment

The gas metal arc welding (GMAW) process was first used in the early 1920s to increase weld purity and production efficiency. During the early 1950s, it was discovered that carbon dioxide could be used as a shielding gas. This discovery, and the development of more versatile continuous consumable wire electrodes (welding wire), increased the popularity of GMAW.

GMAW equipment consists of a welding gun, wire feeder, and shielding gas. Oxygen, nitrogen, and hydrogen adversely affect the weld, consequently they must be excluded from the weld area during welding. Inert gases, such as argon and helium, do not react readily with other elements, making them useful as shielding gases for arc welding. A GMAW weld can be applied by the semiautomatic, mechanized, or automatic processes.

GAS METAL ARC WELDING

Gas metal arc welding (GMAW) is an arc welding process that uses an arc between a continuous wire electrode and the weld pool. The continuous wire electrode (welding wire) is fed through the welding gun at a preset, controlled speed. A shielding gas, supplied from an external source, is also fed through the welding gun. The shielding gas completely covers and protects the weld pool. The GMAW process, also called MIG welding, does not require a flux covering to provide shielding of the weld area. The weld area is protected by the shielding gas.

When semiautomatic welding is used, the wire feed speed, power setting, and gas flow are preset, but the welding gun is manually operated. The welder directs the welding gun along the weld joint to complete the weld.

A constant-voltage welding machine with direct current electrode positive is most commonly used when welding with GMAW.

GMAW CURRENT SELECTION

The most common current selected for GMAW welding is DCEP. DCEP is the most efficient since the heat is concentrated at the weld pool, providing deep penetration. DCEP also provides greater surface cleaning, which is important when welding metals that can develop an oxide layer.

A wide range of current values can be used for GMAW. Current is selected based on metal thickness. One wire size can weld various metal thicknesses, which permits welding without having to change welding wire diameter. The correct current to use for a particular joint must often be determined by trial and error. The current selected should be high enough to allow the desired penetration without cold lapping but low enough to prevent undercutting and melt-through. See Appendix. Once the current is selected, it will be maintained at a constant level.

DCEP provides deep penetration and excellent cleaning action.

DCEN should not be used for GMAW because weld penetration is shallow and wide; there is excessive spatter; and no surface cleaning occurs. DCEN is also ineffective because metal transfer is erratic and globular. See Figure 19-1. AC current should not be used with GMAW since burn-offs are unequal on each half-cycle.

Welding current has a great effect on the weld deposited using GMAW. The welding current limits the wire feed speed to a definite range. However, it is possible to adjust the wire feed speed within the range. For a specific current setting, a high wire feed speed results in a short arc. A low wire feed speed contributes to a long arc. A lower feed speed must be used for welding in overhead position than for welding in flat position to prevent the weld pool from running out of the weld area. See Appendix.

GMAW WELDING MACHINES

Welding machines used for GMAW should supply DC current up to 250 A to cover most welding tasks. During welding, heat is generated by the flow of current across the gap between the end of the welding wire and the workpiece (arc length). The voltage across the gap varies with the length of the arc. To produce a uniform weld, the welding voltage and arc length must remain constant. This can be accomplished by (a) feeding welding wire into the weld zone at the same rate at which it melts, or (b) melting welding wire at the same rate at which it is fed into the weld zone.

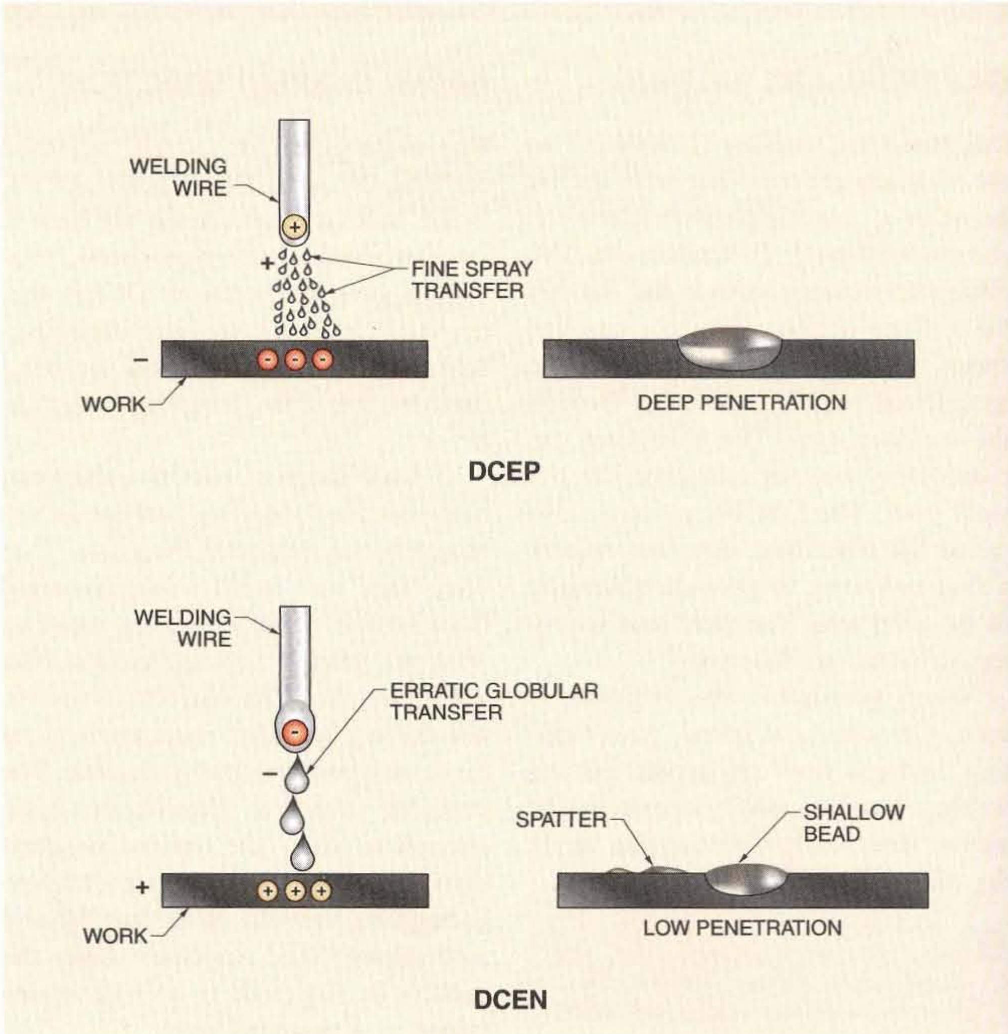


Figure 19-1. *DCEP should be used for GMAW as it provides better penetration. DCEN results in low penetration and excessive spatter.*

Constant-Voltage Welding Machines

Constant-voltage (constant-potential) welding machines are commonly used for GMAW. Potential is synonymous with voltage. *Constant potential* is the generation of a stable voltage regardless of the current output produced by the welding machine. A constant-voltage welding machine has a nearly flat volt-ampere characteristic. See Figure 19-2. This means that the preset voltage level can be held constant during welding. Although its static electrical potential at open circuit is lower than a welding machine with a drooping characteristic, a constant-voltage welding machine maintains approximately the same voltage regardless of the amount of current drawn. Accordingly, there is unlimited current to melt the welding wire.

Constant-Voltage Welding Machine
Figure 19-2

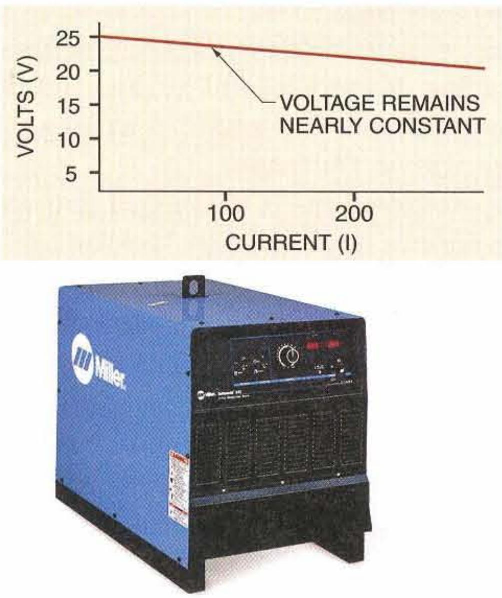


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Figure 19-2. *A constant-voltage welding machine has a nearly flat volt-ampere curve.*

Many constant-voltage welding machines used for GMAW have an average, "fixed" amount of slope built into the circuit to allow for good short circuiting transfer.

There are only two basic controls on a constant-voltage welding machine: a rheostat on the welding machine to regulate the voltage, and a rheostat on the wire feeder to control the speed of the wire feed motor. There is no current control on a constant-voltage welding machine: the welding current output is determined by the wire feed speed.

A constant-voltage welding machine is self-correcting with respect to arc length and provides the necessary current required by the load imposed upon it. When welding wire is fed into the arc at a specific rate, a proportionate amount of current is automatically drawn. The operator can change the wire feed speed over a considerable range without affecting stubbing or burn-back of the wire. In other words, the arc length can be set on the welding machine and any variations in nozzle-to-work distance will not produce changes in the arc length. For example, if the arc length becomes shorter than the preselected value, there is an automatic increase of current and the wire speed automatically adjusts itself to maintain a constant arc length. Similarly, if the arc becomes too long, the current decreases and the welding wire feeds faster.

For GMAW, a constant-voltage welding machine with a nearly flat volt-ampere characteristic maintains a constant, preset voltage level during welding.

Slope Control. *Slope* is the shape of the volt-amp curve on a GMAW welding machine. By altering the flat shape of the V/A current, it is possible to control the pinch force on the welding wire, which is particularly important when using short circuiting transfer. With better control of the short circuiting transfer mode, the weld pool can be kept more fluid. Slope control also helps to decrease the sudden current surge that occurs when the electrode initially contacts the workpiece. By slowing the rate of current rise, spatter can be reduced. Some older model welding machines designed for GMAW have a slope control. Newer models have either a fixed slope or a slope reactor control built in.

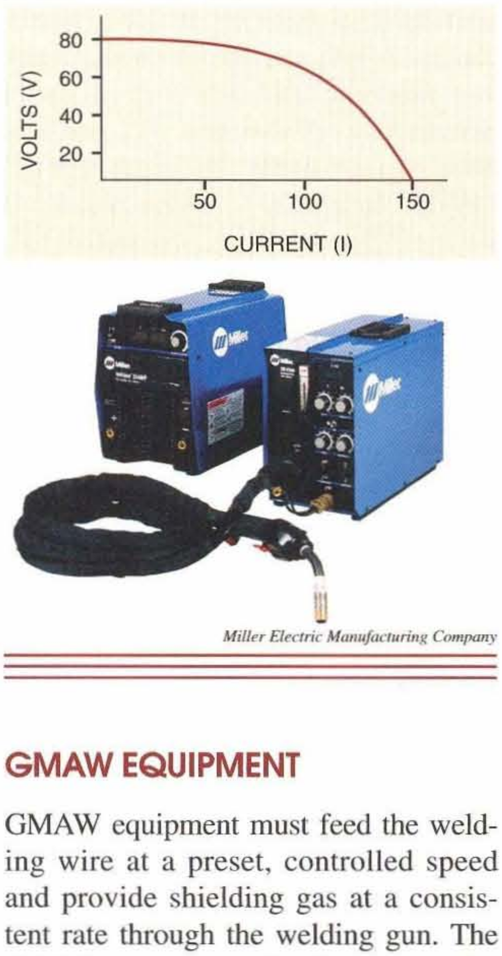
Constant-Current Welding Machines

A constant-current welding machine produces a current that remains constant over a range of welding voltages. The current has a steep slope and a drooping volt-ampere characteristic. See Figure 19-3.

A constant-current welding machine is rarely used for GMAW; however, if it is used, the wire feed speed must be carefully set to prevent the welding wire from burning back to the nozzle or plunging into the workpiece.

Figure 19-3. *A constant-current welding machine produces a constant current over a range of welding voltages.*

Constant-Current Welding Machine
Figure 19-3



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GMAW EQUIPMENT

GMAW equipment must feed the welding wire at a preset, controlled speed and provide shielding gas at a consistent rate through the welding gun. The shielding gas completely covers the weld pool.

A GMAW weld can be applied by the semiautomatic, mechanized, or automatic processes. When semiautomatic welding is used, the wire feed speed, power setting, and gas flow are preset, but the welding gun is manually operated. The welder directs the welding gun along the weld joint, maintaining the proper stickout and travel speed.

In addition to a welding machine, GMAW equipment consists of a welding gun, wire feeder, and shielding gas. See Figure 19-4. Additional equipment may be added to automate the system.

Welding Guns

A welding gun conducts the welding wire, shielding gas, and welding current to the weld area. For welding to occur, the welding gun must maintain electrical contact with the welding wire. A copper-base alloy contact tip within the welding gun conducts the welding current to the welding wire. Current is routed through the welding leads to the contact tip in the welding gun. Contact tips are available with different hole sizes, depending on the diameter of the welding wire. The welding wire is also fed through the electrode lead. The welding leads should be kept as straight as possible to prevent kinking or flattening of the wire roll guides, and to prevent stubbing and bird nesting of he wire in the feeder.

Shielding gas is transported through a separate hose within the welding lead. A shielding gas connection and nozzle on the gun direct the shielding gas to the arc and the weld pool. Cooling of the welding gun is required to prevent overheating. Cooling is provided by the shielding gas or by water circulating through the gun, or both. The welding leads must not become kinked or damaged, as restricted flow of welding wire or shielding gas may occur.

Welding gun parts include the handle, contact tip, gas nozzle, and trigger. The handle allows easy positioning of the gun by the operator. The contact tip conducts electricity from the welding lead to the welding wire as the welding wire leaves the welding gun.

GMAW Equipment
Figure 19-4

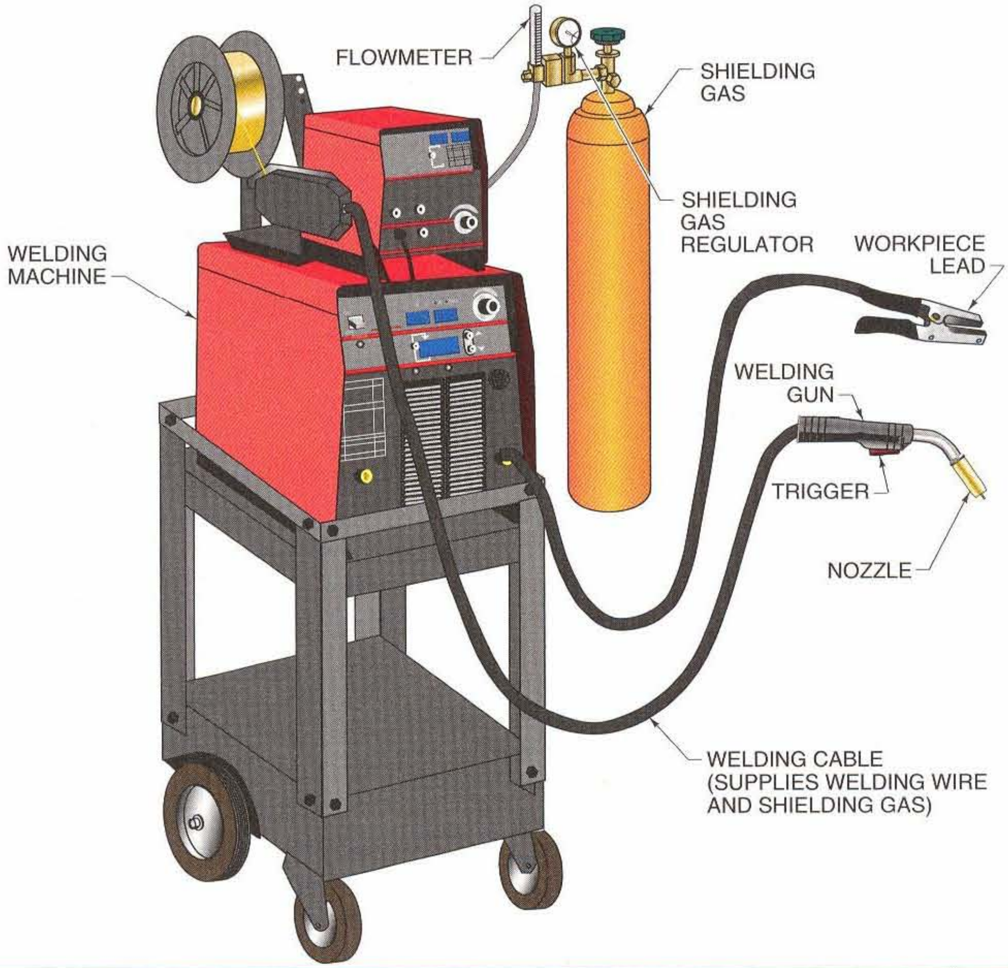

Figure 19-4. *GMAW equipment consists of a welding machine, wire feeder, welding gun, and a shielding gas supply.*

The gas nozzle directs the flow of shielding gas to the weld. Gas nozzle size and shape may vary. Welding guns are available with curved or straight nozzles. See Figure 19-5. The trigger on the welding gun starts and stops welding. When the trigger is pulled, the current, shielding gas flow, and wire feed are activated.

The regulator delivers a steady preset flow of shielding gas to the weld area. The flowmeter indicates the rate of flow (pressure) of shielding gas from the tank to the pressure required by the welding operation. The working pressure is converted into gas flow, which is expressed in cubic feet per hour (cfh). The amount of shielding gas required is determined by the type of welding gun, weld joint, base metal, and conditions of the weld area.

GMAW Welding Guns
Figure 19-5

CURVED

Miller Electric Manufacturing Company

STRAIGHT

Bernard Welding Equipment Company

Figure 19-5. *Welding guns used in GMAW are available with straight or curved nozzles designed for easy access to the weld area.*

For example, welding performed in windy conditions requires more shielding gas flowing to the weld than welding performed in a weld shop.

Semiautomatic Welding Guns. A semiautomatic welding gun allows the welder to manually control and direct welding wire to the joint. Semiautomatic welding guns are manufactured in many shapes and sizes. Many factors determine the correct semiautomatic welding gun to use for a particular welding task. The welding gun and electrode lead are part of the basic welding electrical circuit. A welding gun capable of providing sufficient current for the welding task must be selected. Semiautomatic welding guns are rated to operate between 150 A and 750 A.

A hand-held semiautomatic welding gun commonly has a curved nozzle. The curved nozzle is used for most welding positions and provides easy access to intricate joints and difficult-to-weld patterns. Nozzles are commonly made of copper because copper can conduct away the intense heat that builds up near the arc. Nozzles are available with orifice diameters from $3/8''$ to $7/8''$, depending on the size of the weld pool, the gas shielding required, and the weld joint design.

Ensure that the wire feed speed is set for the current to be used for welding.

A semiautomatic welding gun attaches to the welding cable, which contains the electrode lead, liner, and shielding gas and/or water hoses. Welding wire is fed to the welding gun through a liner. The liner allows the smooth flow of welding wire through the welding cable. Semiautomatic welding guns can be air-cooled or water-cooled. The shielding gas and/or water hoses that run through the welding cable provide shielding gas and cooling to the weld area.

The trigger on a semiautomatic welding gun controls the welding wire feed start, the arc, and the shielding gas flow. The machine controls are set and control the actual feed speed. When the trigger is released, the wire feed, arc, and shielding gas flow stop immediately. A timer is included on some equipment to permit the shielding gas to continue to flow for a predetermined time after the arc is stopped to protect the weld as it solidifies. A water-cooled welding gun has two additional connections for Water In and Water Out to control water flow.

Automatic Welding Guns. Automatic welding guns have a design similar to semiautomatic welding guns, but the gun is usually mounted to a fixture directly below the wire feeder. The fixture may move the welding gun, the worktable, or both. An automatic welding gun does not usually have a trigger; rather, the welding gun is energized from a control panel or remote pendant. Automatic welding guns may be rated up to 1200 A. An air-cooled welding gun is used for welding at low currents, while a water-cooled welding gun is used for welding at high currents. Automatic welding guns are typically water-cooled because of the high currents and duty cycles at which they operate.

Wire Feeder

A wire feeder automatically advances the welding wire from the wire spool to the welding gun and the arc. The wire feed control panel can be adjusted to vary the wire feed speed. In addition, the control panel usually includes a welding power contact tip and a solenoid to energize the gas flow. The wire feeder can be mounted on the welding machine, or positioned elsewhere for convenience. See Figure 19-6.

The wire feeder must be selected to match the power source used for the GMAW application. Constant-speed wire feeders are typically used with constant-voltage welding machines. When using pulsed spray transfer, a controllable wire feeder may be preferable.

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Figure 19-6. *The wire feeder can be mounted on the welding machine, or positioned elsewhere for convenience.*

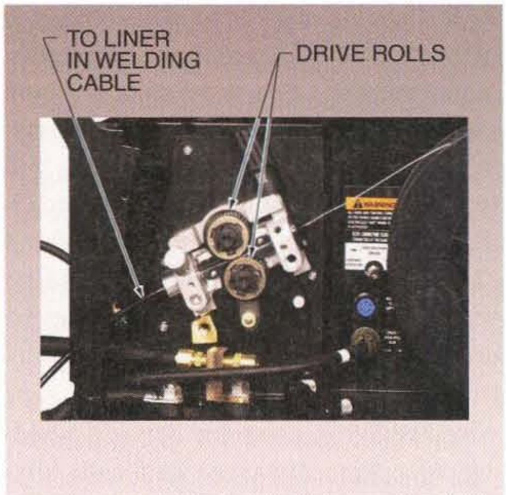

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Figure 19-7. *The drive rolls and liner in the wire feeder must be properly aligned to ensure a consistent welding wire feed without bird nesting.*

A wire feeder consists of an electric motor connected to a gearbox with drive rolls in it. Some systems have four drive rolls; many systems have only two. In a four-roll system, the lower two rolls drive the wire and have a circumferential V-groove. The upper rolls are either smooth, knurled, or have a V-groove in them, depending on the size and type of wire used. The wire feeder may be portable, mounted on the welding machine, or mounted elsewhere to facilitate welding in a large area.

The drive rolls and the liner must be properly sized, based on the welding wire size. The liner must be aligned closely with the groove in the drive roll, without touching. See Figure 19-7. If the liner and the groove are misaligned, bird nesting can occur. *Bird nesting* is the tangling of welding wire in the drive roll as a result of misalignment between the drive roll and the liner or a restriction at the gun end.

The wire feeder feeds the welding wire through the liner to the welding gun at a specified rate. The wire feeder can be a push, pull, or push-pull type, depending on the location of the drive rollers. In the push type, the welding wire is threaded through the drive rollers and pushed through the welding wire lead to the welding gun.

In the pull type, the welding wire is fed through the liner and pulled by drive rollers located on the welding gun. The push-pull type has drive rollers located before and after the liner.

The type of wire feeder used is determined by the characteristics of the welding wire. Small-diameter, soft aluminum welding wire must be pulled through the electrode lead. Large-diameter electrodes often require the push-pull type feeder for consistent flow of wire. In all types of wire feeders, the drive rollers increase or decrease speed as adjusted by the welder. The rate of wire speed is expressed in inches per minute (ipm). An inch button allows the welder to advance or retract the welding wire at a slow speed when changing spools or if a welding wire feeding problem occurs.

Push Type. The most common wire feeder for steel is the push type wire feeder. A push type wire feeder consists of drive rolls that guide the welding wire through the wire feeder and then push it through the liner to the welding gun. The the liner can be up to approximately 12′ for steel wire or 6′ for aluminum wire. The push type wire feeder can handle large-diameter welding wire and hard wire such as carbon and stainless steel in welding conditions where current is over 250 A.

Pull Type. A pull type wire feeder is often used for mechanized and automatic welding. The drive rolls are built into the welding gun and pull the welding wire from the wire feeder. A pull type wire feeder works best with small-diameter welding wire (up to about .045″ in diameter) and soft welding wire. A pull type wire feeder can be used with any hand-held welding gun.

Push-Pull Type. The push-pull type wire feeder is used for driving welding wire long distances and with low-strength welding wires. The push-pull wire feeder has synchronous drive motors that push the welding wire from the wire feeder through the liner, and pull it through the welding gun.

Stickout is the distance the welding wire projects from the end of the nozzle of the welding gun.

Stickout. Stickout for GMAW is the distance the welding wire projects from the end of the gas nozzle. Stickout influences the welding current since it changes the preheating of the welding wire. As stickout increases, a higher resistance value occurs on the length of welding wire beyond the contact tip. The longer the welding wire that is unmelted, the more preheating occurs. Longer stickout lengths require less welding current to melt the electrode at a constant wire feed speed. Since the welding machine is self-regulating, the current output is automatically decreased. Conversely, if stickout decreases, the welding machine must furnish more current to burn off the welding wire at the required rate. See Figure 19-8.

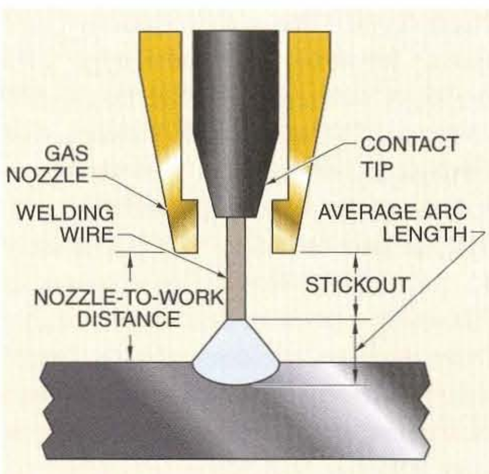


Figure 19-8. *Correct wire stickout is necessary to control the characteristics of the welding wire in the weld pool.*

For most GMAW applications, stickout should measure from 3/8″ to 3/4″. Excessive stickout results in increased wire preheating, which tends to increase the deposition rate. Excessive stickout may also produce a ropy appearance in the weld bead. Too little stickout causes the welding wire to fuse to the contact tip, which decreases the life of the tip. As stickout increases, it may become difficult to follow the weld seam, particularly with small-diameter wire. When working with small-diameter wire, the contact tip should be flush with the gas nozzle or recessed in the nozzle.

The wire, in a near-plastic state between the contact tip and the arc, tends to whip around in a somewhat circular pattern. Decreasing the stickout and straightening the welding wire help decrease the amount of wire whip.

Shielding Gas

The proper nozzle-to-work distance must be maintained to ensure adequate shielding gas coverage.

The shielding gas used has a great effect on the properties of the weld deposit. The air in the weld area is displaced by the shielding gas to prevent it from contacting the weld pool. The arc is then started under a blanket of shielding gas and welding can occur. Since the weld pool is exposed only to the shielding gas, it is not contaminated, and strong, dense weld deposits are obtained. The nozzle-to-work distance of the welding gun must be maintained to ensure an adequate shielding gas cover.

Air is made up of 21% oxygen, 78% nitrogen, .94% argon, and .04% other gases (primarily carbon dioxide). The atmosphere will also contain a certain amount of water depending on its humidity. The elements of air that cause difficulties for welding are oxygen, nitrogen, and hydrogen. Oxygen is a highly reactive element and readily combines with other elements in a metal or alloy to form oxides and gases. The

oxide-forming characteristic of oxygen can be overcome by using deoxidizers in the weld metal.

The effects of oxygen, nitrogen, and hydrogen on the weld make it essential that they be excluded from the weld area during welding. If deoxidizers are not provided, oxygen combines with the iron and forms a compound that can lead to inclusions in the weld, harming the mechanical properties of the metal. As a weld solidifies, the free oxygen in the arc area combines with the carbon of the alloy material, forming carbon monoxide. If the carbon monoxide gas is trapped in the weld, it collects in pockets, causing pores or hollow spaces in the weld. Deoxidizers such as manganese and silicon combine with oxygen and form a light slag that floats to the top of the weld pool, removing oxygen from the weld.

Nitrogen that is introduced into the weld pool causes the most serious problems when welding steel. When iron is molten, it is capable of taking in a relatively large amount of nitrogen. At room temperature, the solubility of nitrogen in iron is very low. During cooling, the nitrogen precipitates or comes out of the iron as nitrides. Nitrides increase hardness in the iron, but also cause a decrease in ductility and impact resistance. The loss of ductility often leads to cracking in and near the weld. In excessive amounts, nitrogen can also lead to porosity in the weld.

Hydrogen is harmful to welding because small amounts of hydrogen in the atmosphere can cause an erratic arc if allowed to enter the weld pool. Hydrogen also has an effect on the properties of the weld. Iron can hold a relatively large amount of hydrogen when it is molten, but when the iron cools, it can no longer hold dissolved hydrogen. As the weld metal solidifies, the hydrogen comes out of solution. Hydrogen that becomes entrapped in the solidifying metal and heat-affected zone. These pressures lead to minute cracks in the weld metal that can develop into large cracks. Hydrogen also causes defects known as fisheyes and underbead cracking.

Atmospheric gases can be excluded using an inert gas for shielding. Inert gases consist of atoms that are stable and do not react readily with other materials, making them useful as shielding gas for arc welding. Only six elements, helium, neon, argon, krypton, xenon, and radon, possess the stability required for use as a shielding gas. Of the six, only argon and helium are available in sufficient quantities for welding at an economical price. See Figure 19-9.

Although it is not an inert gas, carbon dioxide gas can also be used for shielding the weld area if compensation is made for its oxidizing tendencies. Carbon dioxide, argon, and helium can be used in their pure form or mixed for a specific application.

Carbon Dioxide. Unlike argon or helium gases, which are made up of single atoms, carbon dioxide gas is made up of molecules. Each molecule contains one carbon atom and two oxygen atoms. The chemical formula for the carbon dioxide molecule is CO_2. Often, carbon dioxide is referred to simply as "C-O-TWO."

The use of CO_2 as a shielding gas is most effective and least expensive when welding steel.

Carbon dioxide is found in most plants in flue gases that are given off by the burning of natural gas, fuel oil, or coke. It is also obtained as a byproduct of calcining operations of limekilns, from the manufacturing of ammonia, and from the fermentation of alcohol. The CO_2 given off by the manufacturing of ammonia and the fermentation of alcohol is almost 100% pure.

The purity of CO_2 can vary considerably, depending on the process used to manufacture it. Standards have been established for CO_2 purity suitable for arc welding. The purity specified for

welding-grade CO_2 is a minimum dew point of –40°F. Gas of this purity contains approximately .0066% moisture by weight. Manufacturers commonly produce CO_2 with a dew point as low as –70°F.

At normal temperatures, CO_2 is essentially an inert gas. However, when subjected to high temperatures, CO_2 dissociates into carbon monoxide and oxygen. In the high temperature of welding, this dissociation takes place to the extent that 20% to 30% of the gas in the arc area is oxygen (O_2). Because of the oxidizing characteristic of CO_2 gas, the welding wire used with CO_2 must contain deoxidizing elements. The deoxidizing elements have a great affinity for and readily combine with oxygen, preventing the oxygen atoms from combining with carbon or iron in the weld metal and producing low-quality welds. The most common deoxidizers used in welding wire are manganese, silicon, aluminum, titanium, and vanadium.

Carbon dioxide may be used for GMAW because it eliminates many of the undesirable characteristics of argon used as a shielding gas. With CO_2 a broad, deep penetration is obtained, making it easier for the operator to eliminate weld defects such as lack of penetration and lack of fusion. Bead contour with CO_2 is good and there is no tendency toward undercutting. Another advantage is its relatively low cost compared to other shielding gases.

While manufacturers generally use color codes to identify gas cylinders, colors may not be consistent between suppliers. Always check the cylinder for contents before attaching and using a gas cylinder.

GMAW SHIELDING GASES		
Material	**Preferred Gas**	**Remarks**
Aluminum Alloys	Argon	With DCEP, removes oxide surface on workpiece
Magnesium Aluminum Alloys	75% He 25% Ar	Greater heat input reduces porosity tendencies. Also cleans oxide surface
Stainless Steels	Argon + 1% O_2	Oxygen eliminates undercutting when DCEP reverse polarity is used
	Argon + 5% O_2	When DCEN, is used, 5% O_2 improves arc stability
Magnesium	Argon	With DCEN, removes oxide surface on workpiece
Copper (deoxidized)	75% He, 25% Ar (Argon)	Good wetting and increased heat input to counteract high thermal conductivity. Light-gauge metals
Low-Carbon Steel (Mild Steel)	Argon + 2% O_2	Oxygen eliminates undercutting tendencies; also removes oxidation
Low-Carbon Steel (Mild Steel)	80% Argon min. (spray transfer)	High-quality, low-current, out-of-position welding, low spatter
Nickel	Argon	Good wetting, decreases fluidity of weld metal
Monel®	Argon	Good wetting, decreases fluidity of weld metal
Inconel®	Argon	Good wetting, decreases fluidity of weld metal
Titanium	Argon	Reduces heat-affected zone, improves metal transfer
Silicon Bronze	Argon	Reduces crack sensitivity
Aluminum Bronze	Argon	Less penetration of base metal. Commonly used as a surfacing material

NOTE: ( ) = Second Choice

Figure 19-9. *Inert gases such as argon and helium are stable gases that do not readily react with other atoms, making them suitable as shielding gases for GMAW.*

A drawback of CO_2 gas is the tendency for the arc to be somewhat violent. This can lead to spatter problems when welding thin metals where appearance is important. For most applications, spatter is not a major problem and the advantages of CO_2 as a shielding gas outweigh its disadvantages; however, when preventing spatter is important, an anti-spatter spray can be used. Anti-spatter sprays can be used with GMAW to prevent spatter from sticking to the nozzle, gas cup, and base metal. Carbon dioxide is used primarily for mild steel welding, although it may be used in other shielding gas mixtures.

Many GMAW welding guns may be used at 100% duty cycle with CO_2 as the shielding gas at a particular current setting; however, using the same welding gun with argon as the shielding gas, a lower current setting must typically be used for a 100% duty cycle.

Argon. Argon has been used for many years as a shielding gas. Argon is obtained through the liquefaction and distillation of air. To manufacture argon, air is put under intense pressure and refrigerated to a very low temperature. The temperature is then raised until the various elements in the air are boiled off. Argon boils off at a temperature of –302.4°F (–185.9°C). The resulting purity of the argon used for welding is approximately 99.995%. When greater purity is required, the gas can be chemically cleaned to a purity of 99.999%.

Argon has a relatively low ionization potential, which means that the welding arc tends to be more stable when argon is used as the shielding gas. Argon is often mixed with other gases to improve their stability. Argon reduces spatter, producing a quiet arc. Since argon has a low ionization potential, the arc voltage is reduced when an argon mixture is used as a shielding gas. This results in lower power in the arc and lower penetration of the weld. The combination of lower penetration and reduced spatter makes the use of argon desirable when welding sheet metal.

Straight argon is seldom used as a shielding gas except when welding metals such as aluminum, copper, nickel, and titanium. When welding steel, the use of straight argon leads to undercutting and poor bead contour. Additionally, penetration with straight argon is shallow at the bead edges and deep at the center of the weld, which can lead to lack of fusion at the root of the weld.

Helium. Helium is derived from natural gas. The process by which it is obtained is similar to that of argon. First, the natural gas is compressed and cooled. Helium distills from natural gas at a temperature of –452°F (–269°C). Helium is lighter than air and has high thermal conductivity. The helium arc plasma will expand under heat (thermal ionization), reducing the arc density.

With helium there is a simultaneous change in arc voltage where the voltage gradient of the arc length is increased by the discharge of heat from the arc stream or core. This means that more arc energy is lost in the arc itself and is not transmitted to the work. The result is that, with helium, there will be a broader weld bead than with argon, with relatively shallow penetration. (For GTAW, the opposite is true.) The energy lost in the arc also accounts for the higher load voltage for the same arc length that is obtained with helium as opposed to argon.

Argon, or a mixture of argon and oxygen, produces the most effective results when welding aluminum and stainless steel.

Helium at times has been in short supply due to governmental restrictions and, therefore, has not been used for welding as much as it might have been. Because of its high cost, helium is used primarily for special welding tasks and for nonferrous metals such as aluminum, magnesium, and copper. It is also used in combination with other shielding gases.

Argon-Oxygen. To reduce the poor bead contour and penetration obtained with argon when welding on mild steel, oxygen is added to the shielding gas. A small amount of oxygen added to argon produces significant changes. Normally, oxygen is added in amounts of 1%, 2%, or 5%. Using GMAW welding wire, the amount of oxygen that can be used is limited to 5%. Adding oxygen in amounts greater than 5% may lead to porosity in the weld.

Oxygen improves penetration by broadening the deep penetration finger at the center of the weld bead. It also improves bead contour and eliminates the undercutting at the edge of the weld that occurs with pure argon. Argon-oxygen mixtures are common for welding alloy steel, carbon steel, and stainless steel.

Argon-CO_2. For some mild steel welding applications, welding-grade CO_2 does not provide the required arc characteristics. This is usually evident in the form of spatter in the weld area. Using an argon-CO_2 mixture can usually eliminate the problem. Some welding professionals believe that the mixture should not exceed 25% CO_2; others feel that mixtures with up to 80% CO_2 are acceptable.

For most welding, the gas flow rate is approximately 20 cfh to 35 cfh.

Information on a gas cylinder label typically includes the type of gas or mixture of gas contained, and the manufacturer or supplier name.

Premixed argon-CO_2 costs the same as pure argon, whereas the price of CO_2 is approximately 15% that of argon, making it more economical to buy the CO_2 separately and mix it at the job site or shop. Mixture percentages for each gas cylinder are regulated using flowmeters. Using separate gas cylinders eliminates the gas separation that may occur in premixed cylinders. An argon-CO_2 shielding gas mixture is used for welding mild steel, low-alloy steel, and, in some cases, stainless steels.

Argon-Helium-CO_2. An argon-helium-CO_2 shielding gas mixture is used for welding austenitic, martensitic, and ferritic stainless steels. The combination of gases provides a unique characteristic to the weld. It is possible to make a weld with very little buildup of the top bead profile. An argon-helium-CO_2 mixture is used for applications where a high-crowned weld is detrimental.

Gas Flow Rates. For most welding, the gas flow rate is approximately 20 cfh to 35 cfh. The flow rate may be increased or decreased, depending on the type and thickness of metal and the particular welding application. See Appendix.

Flow rate settings are not absolute, but a starting point in making settings. Final adjustments must often be made on a trial-and-error basis. The correct settings are determined by the type and thickness of metal to be welded; the position of the weld; the shielding gas used; the electrode diameter; and the type of joint.

Proper gas shielding usually results in a rapid, crackling or sizzling arc sound. Inadequate gas shielding produces a popping arc sound and results in a discolored weld, porosity, and spatter.

Gas drift may occur with high travel speeds or in unusually drafty or windy job site conditions around the weld area. Gas drift commonly results in

inadequate gas shielding. The gas nozzle should be adjusted for proper shielding and outside influences should be eliminated by using proper windbreaks or shields. See Figure 19-10.

The distance from the work to the gas nozzle is determined by the nature of the weld. The gas nozzle is usually placed up to 2″ from the work. Too much space between the gas nozzle and the work reduces the effectiveness of the gas shield, while too little space may result in excessive weld spatter, which collects on the gas nozzle and shortens its life.

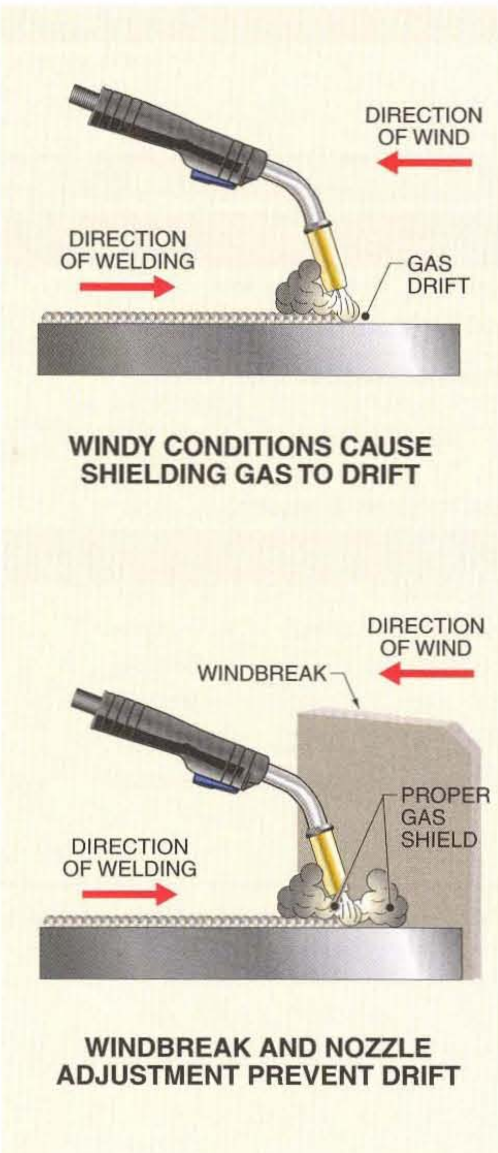


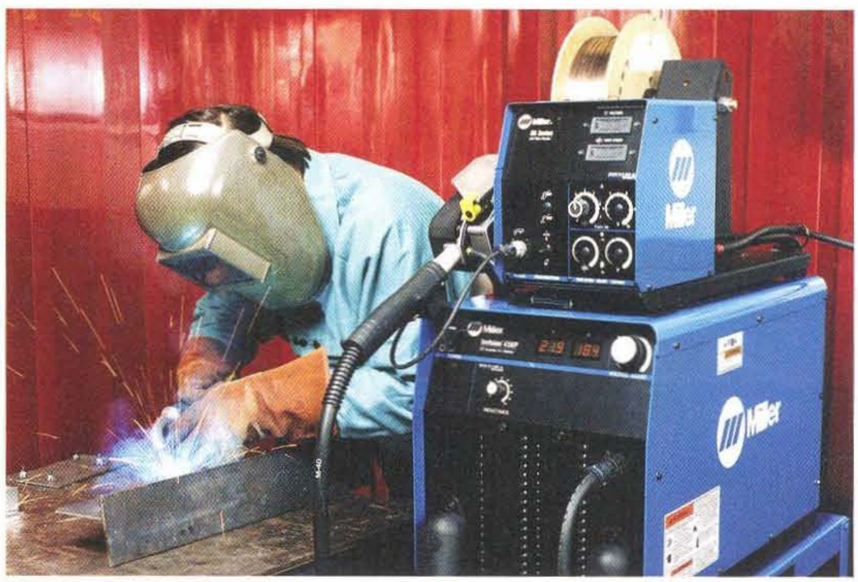
Figure 19-10. *High travel speeds and windy conditions can cause the shielding gas to drift away from the arc. Windbreaks or moving the nozzle closer to the weld can help control drift.*

GMAW WELDING WIRE

Welding wire for GMAW should be similar in composition to the base metal. Welding wire designations correspond to the welding application. Welding wire designations are based on AWS classifications. For mild steel welding wire, the E identifies it as an electrode and an R identifies it as a rod. The second and third digits show the tensile strength in psi per thousand, the S indicates a solid bare wire, and the final symbols specify a particular classification based on chemical composition of the welding wire. See Figure 19-11.

Basic welding wire diameters include .020″, .030″, .035″, .045″, .052″, 1/16″, and 1/8″. Generally, welding wire of .020″, .030″, or .035″ is best for welding thin metal, although it can be used to weld low- and medium-carbon steel and medium-thickness, high-strength/low-alloy (HSLA) steel. Medium-thickness metal normally requires .045″ or 1/16″ diameter welding wire. For thick metal, 1/8″ welding wire is usually recommended. See Figure 19-12. The welding position to be used is a factor that must be considered when selecting welding wire. For vertical or overhead welding, small-diameter wires are more acceptable than large-diameter wires.

The correct diameter wire must be used to ensure a quality weld. Check the wire manufacturer recommendations for correct wire diameters.



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Welding wire is selected to match the composition of the metal to be welded. Welding wire designations are based on AWS classifications.

WELDING WIRE FOR GMAW	
	Mild Steel
ER-60S-1	Silicon deoxidized wire for low- and medium-carbon steels. Can be used with either CO_2, argon, or argon-CO_2 mixtures. Performs best on killed steels
ER-60S-2	Premium quality wire containing Al, Zr, and Ti in addition to silicon and manganese deoxidizers. Can be used with CO_2, argon-CO_2, or argon-O_2. Recommended for pipe welding and heavy vessel construction
ER-60S-3	Used for high-quality welding either with CO_2, argon-O_2, or argon-CO_2 mixtures. Produces medium-quality welds in rimmed steels and high-quality welds in semi-killed steels
ER-70S-1B	Low-alloy wire for carbon steels, low-alloy steels, and high-strength, low-alloy steels
ER-70S-3	General-purpose welding of low- to medium-carbon steels. Has a silicon content high enough to permit its use in either CO_2, argon-O_2 mixtures, or a mixture of the two
ER-70S-6	Contains higher manganese and silicon levels and has more powerful deoxidizing characteristics for welding over rust and scale or where stringent cleaning practices cannot be followed
ER-70S-5	Contains aluminum and is designed for single or multiple pass welding of rimmed, semi-killed, or killed mild steels. Suitable to weld steels having rusty or dirty surfaces. Normally used with CO_2 gases
	Aluminum
ER-1100 ER-4043 ER-5183 ER-5554, 5556 ER-5654	Weld aluminum of similar composition
	Stainless Steel
ER-308L ER-308L-Si	For welding types 304, 308, 321, 347 For welding types 301, 304
ER-309	For welding types 309 and straight chromium grades when heat treatment is not possible Also for 304-clad
ER-310 ER-316 ER-347	For welding types 310, 304-clad, and hardenable steels For welding 316 For welding types 321 and 347 where maximum corrosion resistance is required
	Copper and Copper-Based Alloy
ECuSi (Silicon Bronze) ECuAl-A1 (Aluminum Bronze) ECu (Deoxidized Copper) ECuAl-A2 (Aluminum Bronze) ECuAl-B (Aluminum Bronze)	Special wires for welding copper and copper-based alloys

Figure 19-11. *Welding wire should be of a similar material to the base metal and must be chosen depending on the type of welding to be performed.*

WELDING WIRE DIAMETERS					
Metal Thickness*	Wire Size*	Welding Conditions (DCEP) (arc volts)	(amperes)	Gas Flow†	Travel Speed‡
.025	.030	15 – 17	30 – 50	15 – 20	15 – 20
.031	.030	15 – 17	40 – 60	15 – 20	18 – 22
.037	.035	15 – 17	65 – 85	15 – 20	35 – 40
.050	.035	17 – 19	80 – 100	15 – 20	35 – 40
.062	.035	17 – 19	90 – 110	20 – 25	30 – 35
.078	.035	18 – 20	110 – 130	20 – 25	25 – 30
.125	.035	19 – 21	140 – 160	20 – 25	20 – 25
.125	.045	20 – 23	180 – 200	20 – 25	27 – 32
.187	.035	19 – 21	140 – 160	25 – 30	14 – 19
.187	.045	20 – 23	180 – 200	25 – 30	18 – 22
.250	.045	19 – 21	140 – 160	30 – 35	10 – 15
.250	.052	20 – 23	180 – 200	30 – 35	12 – 18

NOTE: Gas flow rates will vary from values shown based on the type of metal welded
Shielding gas CO_2, welding grade
Wire stickout—1/4″ to 3/8″
* in in.
† in cubic feet per hour (cfh)
‡ in in./min

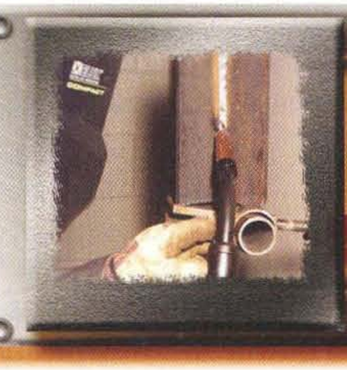
Figure 19-12. *The required welding wire diameter is based on the type of metal to be welded as well as the position of welding.*

POINTS TO REMEMBER

1. DCEP provides deep penetration and excellent cleaning action.
2. For GMAW, a constant-voltage welding machine with a nearly flat volt-ampere characteristic maintains a constant, preset voltage level during welding.
3. Ensure that the wire feed speed is set for the current that is to be used for welding.
4. Stickout is the distance the welding wire projects from the end of the nozzle of the welding gun.
5. The proper nozzle-to-work distance must be maintained to ensure an adequate shielding gas cover.
6. The use of CO_2 as a shielding gas is most effective and least expensive when welding steel.
7. Argon, or a mixture of argon and oxygen, produces the most effective results when welding aluminum and stainless steel.
8. For most welding, the gas flow rate is approximately 20 cfh to 35 cfh.
9. The correct diameter wire must be used to ensure a quality weld. Check the wire manufacturer recommendations for correct wire diameters.

QUESTIONS FOR STUDY AND DISCUSSION

1. What are some of the specific advantages of GMAW?
2. Why is DCEP current used for GMAW?
3. What results can be expected if DCEN current is used?
4. How does a constant-voltage welding machine differ from a constant-current welding machine?
5. What is the advantage of using a constant-voltage welding machine for GMAW?
6. What is meant by slope control?
7. What are the elements that make up air?
8. Why is oxygen generally a harmful element in welding?
9. Why does nitrogen cause the most serious problems in welding?
10. When is argon or an argon-O_2 mixture considered the ideal gas for shielding?
11. When is CO_2 better for shielding than an inert gas?
12. How is it possible to determine the proper gas flow for shielding?
13. What happens if the gas flow is allowed to drift from the weld area?
14. What factors must be taken into consideration in selecting the correct diameter (size) welding wire?
15. How is the welding wire fed to the welding gun?
16. What determines the rate at which the wire feed should be set?
17. Why is the correct stickout important?



GMAW - Procedures

20

Gas Metal Arc Welding (GMAW)

GMAW is a relatively fast welding process with higher deposition rates than SMAW. Many welding applications that were once only performed with SMAW are now being completed with the GMAW process. Pipelines, railroad cars, automobiles, and heavy equipment manufacturing are industries that use GMAW more commonly than SMAW for many welding jobs. When performing GMAW welding outdoors, wind protection may be needed to protect the shielding gases from being blown away from the weld area. Since GMAW has deep penetrating characteristics, narrower beveled joint designs can be used.

GMAW PROCEDURES

GMAW was developed to increase the speed at which weld metal could be deposited. Although GMAW can be fully automated, it is most often semiautomated. When the semiautomatic process is used, the wire feed, power setting, and gas flow are preset, but the welding gun is manually operated. The operator provides manual travel and guidance of the welding gun, directs the welding gun over the weld seam, and maintains the correct wire stickout distance and speed. GMAW has the following advantages over other welding procedures:

- No flux or slag and little spatter are produced, minimizing cleanup time and resulting in a savings in total welding cost.
- Less time is required to train an operator. Welders who are proficient in other welding processes can easily master GMAW. The primary duty is to monitor the angle of the welding gun, the travel speed, and the wire stickout.
- No starting and stopping to change electrodes is required, reducing welding time and eliminating a common cause of weld failures. Welding that starts and stops frequently, such as SMAW, commonly results in slag inclusions, cold lapping, and crater cracking.
- Better metallurgical benefits are imparted to the weld area because of the high travel speed. A faster travel speed results in a narrower HAZ. There is also less grain growth, less heat transfer in the base metal, and reduced distortion.
- GMAW is more economical for welding light-gauge metal when short circuiting transfer is used.
- A narrow beveled joint can be used because of the deep penetrating capabilities of GMAW, reducing the size of fillet welds.

The GMAW process was developed during World War II, when a cost-effective and efficient method of welding thick metals, such as found on ships and tanks, was needed.

GMAW is a faster welding process than SMAW and is easy to learn.

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GMAW is a versatile welding process that allows fast deposition on different metal thicknesses.

Groove joints used for GMAW have small root faces, small root openings, and a narrow groove angle, all of which reduce the joint area, requiring less weld metal.

Joint Preparation

Joint preparation is recommended to aid in penetration of the weld and weld reinforcement control. For GMAW, beveling the edges is usually desirable for butt joints thicker than ¼″ if complete root penetration is desired. For thin metals, a square butt joint is best.

Generally, the joint design recommended for other arc welding processes can be used for GMAW. However, some joint modifications may be required to compensate for the operating characteristics of GMAW. These modifications produce a narrower, more penetrating arc than SMAW. See Figure 20-1. Consequently, groove joints formed with GMAW have smaller root faces and root openings.

Butt Joints. A butt joint typically requires more welding skill than other joints. When making butt joints, distortion and residual stress must be prevented by using the proper fit-up and joint edge preparation. Butt joints have very good mechanical strength if properly prepared.

Lap Joints. A lap joint is commonly used for many welding applications. In a lap joint, the surfaces of the metals to be joined overlap one another. The degree of overlap is determined by the thickness of the metal. Lap joints are usually welded with fillet welds, which results in a weld with good mechanical properties, especially when welded on both sides.

T-Joints. T-joints generally require little, if any, edge preparation. Edges of a T-joint may be left square or may be prepared by grinding or machining. A T-joint typically requires a fillet weld.

Edge Joints. Edge joints are commonly used when the finished weld will not be exposed to excess loads or heavy impact. The edges of the metal to be welded may be left square or beveled by grinding or machining. The grooves created by beveling allow proper penetration of the weld metal.

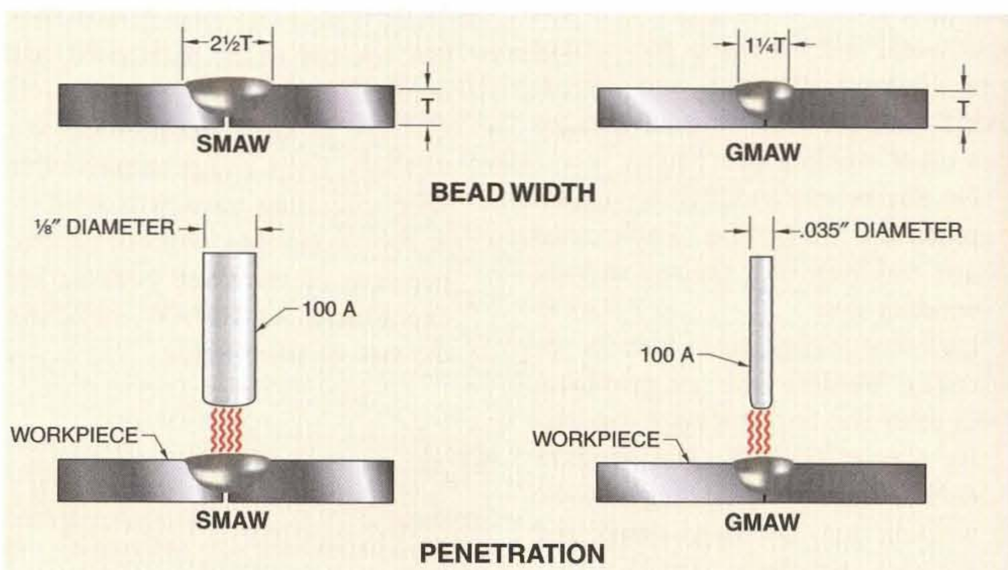


Figure 20-1. *GMAW produces a narrower weld bead and deeper penetration than SMAW, requiring a smaller root face and root opening.*

Corner Joints. Corner joints also require little, if any, edge preparation. After a corner joint is welded, the edges are ground smooth to impart an attractive appearance to the finished weld.

Weld Backing

When using GMAW, weld backing is helpful to obtain a sound weld at the root. Backing is used when complete weld penetration is required. Backing conducts heat away from the joint and forms a mold or dam to prevent the molten metal from running through the joint being welded. There are several types of material used for backing: steel or copper blocks, strips, and bars; carbon blocks; or fired clay. The material most commonly used for backings with GMAW are copper or steel.

Positioning Work and Welding Wire

Proper positioning of the welding gun and the workpieces is necessary to achieve a quality weld. In GMAW, the flat position is typically preferred for most joints because it improves metal flow and bead contour, and provides better shielding gas protection. On gauged metal, it is sometimes necessary to weld with the work inclined 10° to 20°. When the work is inclined, welding is performed downhill. Downhill welding has a tendency to flatten the bead and increase the travel speed.

The welding wire must be properly aligned in relation to the joint. The welding wire should be on the centerline of the joint for most butt joints if the workpieces to be joined are of equal thickness. If the workpieces are unequal in thickness, the welding wire may be moved toward the thicker metal.

Correct work angle and travel angle ensure correct weld bead formation. See Figure 20-2. The travel angle may be a push angle or a drag angle depending upon the position of the welding gun. If the welding gun is angled back toward the beginning of the weld, the travel angle is called a drag angle. A *drag angle* is an angle where the electrode is pointing in the direction opposite of welding. If the welding gun is pointing ahead toward the end of the weld, the travel angle is called a push angle. A *push angle* is a travel angle where the electrode is angled to point in the direction of welding.

Keep the welding gun properly positioned to ensure a uniform weld with proper penetration.

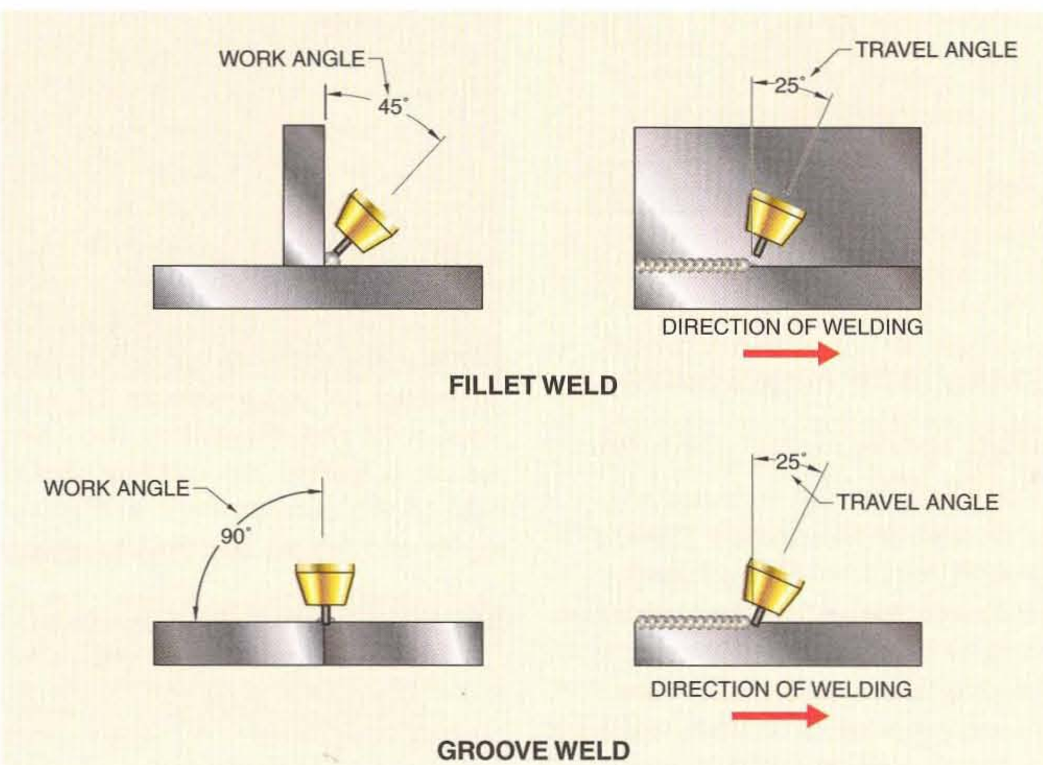


Figure 20-2. *The correct work angle and travel angle are necessary for correct weld bead formation.*

Ensure that the contact tube and gas nozzle orifices are clean to prevent clogging, which restricts wire feed and shielding gas flow.

When the welding gun is ahead of the weld, it is referred to as pulling the weld metal. If the welding gun is behind the weld, it is said to be pushing the weld metal. Generally, the penetration of beads deposited by pulling the welding gun is greater than by pushing the welding gun. In addition, since the welder can see the weld crater more easily by pulling the weld, high quality welds can be produced more consistently. Pushing the weld permits the use of higher welding speeds and produces less penetration and wider welds. See Figure 20-3.

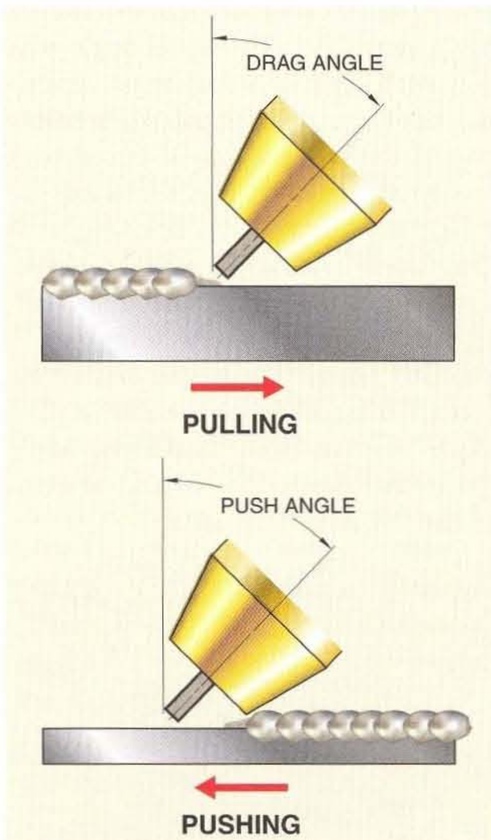


Figure 20-3. *Pulling the weld (drag angle) is preferred for welding thick metals, while pushing the weld (push angle) is used for light-gauge metals.*

GMAW SETUP PROCEDURES

Before starting to weld, the following must be checked:

- Ensure that all electric power controls are in the OFF position.
- Ensure that all hose and cable connections from the welding gun to the wire feeder are in good condition, are properly insulated, and have been correctly secured.
- Use the correct size gas nozzle for the diameter of welding wire used.
- Ensure that the welding wire is properly threaded through the welding gun.
- Ensure that the contact tube and gas nozzle orifices are clean. Blow out the welding gun occasionally since with use it becomes clogged with dust, restricting the wire feed and shielding gas flow.
- Set the predetermined wire feed speed on the wire feeder control.
- Ensure that shielding gas and water coolant sources are on and adjusted on the feeder control.
- Check for wear on contact tip. With use, tips wear out and must be replaced.

During any welding operation, certain welding conditions may have to be changed. Welders should be familiar with common welding variables and the required changes that must be made during welding. See Figure 20-4.

Starting the Arc

Starting the arc for welding involves three factors: electrical contact, arc voltage, and time. To ensure a good arc start, the welding wire must make electrical contact with the work. The welding wire must exert sufficient force on the workpiece to penetrate impurities. See Figure 20-5.

Starting the arc becomes increasingly difficult as stickout increases. A reasonable balance of voltage and current must be maintained to ensure the proper arc and to deposit the weld metal at the best wire-melting rate. Once the arc is started, the welding gun is held at the correct work and travel angles and moved at a uniform speed.

Stickout can be adjusted to alter the current and voltage conducted to the arc. A shorter stickout creates a hotter arc; a longer stickout reduces penetration on thin metals.

WELDING VARIABLES								
Change Required		**Arc Voltage**	**Welding Current***	**Travel Speed**	**Travel Angle**	**Electrode Extension/ Stickout**	**Wire Size**	**Gas Type**
Deeper Penetration			Increase (1)		Drag max. 25°	Decrease (2)	Smaller† (5)	CO_2 (4)
Shallow Penetration			Decrease (1)		Push (3)	Increase (2)	Larger† (5)	A+CO_2
Bead Height and Bead Width	Larger Bead		Increase (1)	Decrease (2)		Increase† (3)		
	Smaller Bead		Decrease (1)	Increase (2)		Decrease† (3)		
	Higher, Narrower Bead	Decrease (1)			Drag (2)	Increase (3)		
	Flatter, Wider Bead	Increase (1)			90° or Push (2)	Decrease (3)		
Faster Deposition rate			Increase (1)			Increase† (2)	Smaller (5)	
Slower Deposition rate			Decrease (1)			Decrease† (2)	Larger (5)	

Key: (1) First choice, (2) Second choice, (3) Third choice, (4) Fourth choice, (5) Fifth choice
* Same adjustment is required for wire feed speed
† When these variables are changed, the wire feed speed must be adjusted so that the welding current remains constant

Figure 20-4. *Welding conditions may change during welding, requiring adjustments to welding variables.*

Figure 20-5. *Electrical contact is necessary to start an arc.*

Welding a Joint

7In general, the GMAW welding procedure follows a definite sequence regardless of the type of welding that is being done. For welding a joint with GMAW, follow the procedure:

1. Set the voltage, wire feed, and shielding gas flow to the standard conditions for the required type of welding.
2. Adjust the welding wire to the proper stickout.
3. Start the arc and move the welding gun at a uniform speed, maintaining the proper work angle. If the arc is not started properly, the welding wire may stick or freeze to the work. If the welding wire sticks or freezes, shut OFF the machine and remove the welding wire from the joint.
4. Move the welding gun along the joint using the pushing or pulling technique. As the welding gun is moved, keep the welding wire at the leading edge of the weld pool. Be sure the welding wire is centered in the shielding gas to ensure adequate shielding. A slight weaving motion is helpful to ensure complete penetration.

Do not remove the welding gun from the weld area until the weld pool has solidified. The shielding gas prevents cracks from developing in the molten weld pool.

5. Release the trigger at the end of the weld to stop the wire feed and interrupt the welding current. Always keep the welding gun over the weld until the shielding gas stops flowing to protect the weld pool until it solidifies.
6. Properly shut down the welding machine when welding is completed:
   a. Turn OFF wire speed control.
   b. Shut OFF shielding gas flow at cylinders.
   c. Squeeze welding gun trigger to bleed the lines.
   d. Shut OFF welding machine.
   e. Hang up welding gun.

METAL TRANSFER MODES

The shielding gas type and welding wire size affect the metal transfer mode used. Metal transfer modes in GMAW are short circuiting transfer, spray transfer, pulsed spray transfer, and globular transfer. The type of metal transfer that occurs depends on welding wire size, shielding gas, arc voltage, and welding current. As current increases, the transfer mode changes from short circuiting to globular and then (with 80% argon) to spray.

Although originally GTAW was considered more practical for welding thin sheet metal because of its lower current, the development of the short circuiting transfer technique makes it possible to weld thin stock equally as effectively and more economically with GMAW.

Short Circuiting Transfer

Short circuiting transfer is best for welding light-gauge metals.

Short circuiting transfer allows thin sections of metal to be welded more easily. *Short circuiting transfer* is a metal transfer mode in which molten metal from consumable welding wire is deposited during repeated short circuits. Short circuiting transfer is the easiest, most common transfer mode used. It is practical for welding in all positions, especially for vertical, horizontal, and overhead welding where control of the weld pool is more difficult. Short circuiting transfer produces shallow weld penetration. Short circuiting transfer is commonly used at current levels below 200 A and with welding wire diameters of .045″ or less. Thin welding wire produces a weld pool that remains relatively small and easily managed, making all-position welding possible.

At the start of the cycle, the welding wire melts into a small globule. An electromagnetic pinch force squeezes the drop from the welding wire. Pinch force is a squeezing power common to all current carriers. The amount and suddenness of the pinch is controlled by the welding machine. As the molten welding wire is transferred to the weld, the drop touches the weld pool before it has broken away from the advancing welding wire and the circuit is shorted, extinguishing the arc. Once the drop of molten wire breaks contact with the unmelted welding wire, the arc reignites. Shorting of the arc pinpoints the effective heat. Shorting occurs from 20 to 200 times a second according to preset controls. The result is a small, relatively cool weld pool that reduces melt-through. Intricate welds are possible in most positions. See Figure 20-6.

In short circuiting transfer, the shielding gas mixture consists of 75% argon, to control spatter, and 25% carbon dioxide, both of which provide increased heat for higher speeds. However, straight CO_2 is also used where bead contour is not particularly important but good penetration is essential.

Spray Transfer

Spray transfer is a metal transfer mode in which molten welding wire is propelled axially across the arc in small droplets. Very fine droplets or particles of welding wire are rapidly projected

through the arc to the workpiece in the direction in which the welding gun is pointed. The droplets are equal to or smaller than the diameter of the welding wire. While in the process of transferring through the welding arc, the metal particles do not interrupt the flow of current and there is a nearly constant spray of metal.

Spray transfer requires a high current density. Spray transfer occurs around 250 A and may require 300 A to 400 A. With the higher current, the arc becomes a steady, quiet column with a well-defined, narrow, incandescent, cone-shaped core within which metal transfer takes place. See Figure 20-7. The use of argon or a mixture of argon and oxygen (minimum 80% argon) is also necessary as a shielding gas for spray transfer. Argon produces a pinching effect on the molten tip of the electrode, permitting only small droplets to form and transfer during the welding process. Spray transfer is particularly useful for welding heavy-gauge metal.

With high heat input, thick welding wire melts readily and deep weld penetration becomes possible. Since individual droplets are small, the arc is stable and can be directed where required.

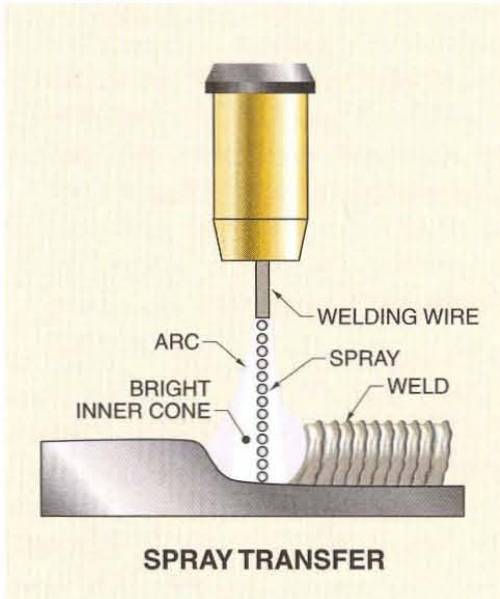


Figure 20-7. *Spray transfer occurs when very fine droplets of welding wire are projected through the arc to the workpiece.*

High current is used with spray transfer to produce a steady, quiet arc with a well-defined core within which metal transfer takes place.

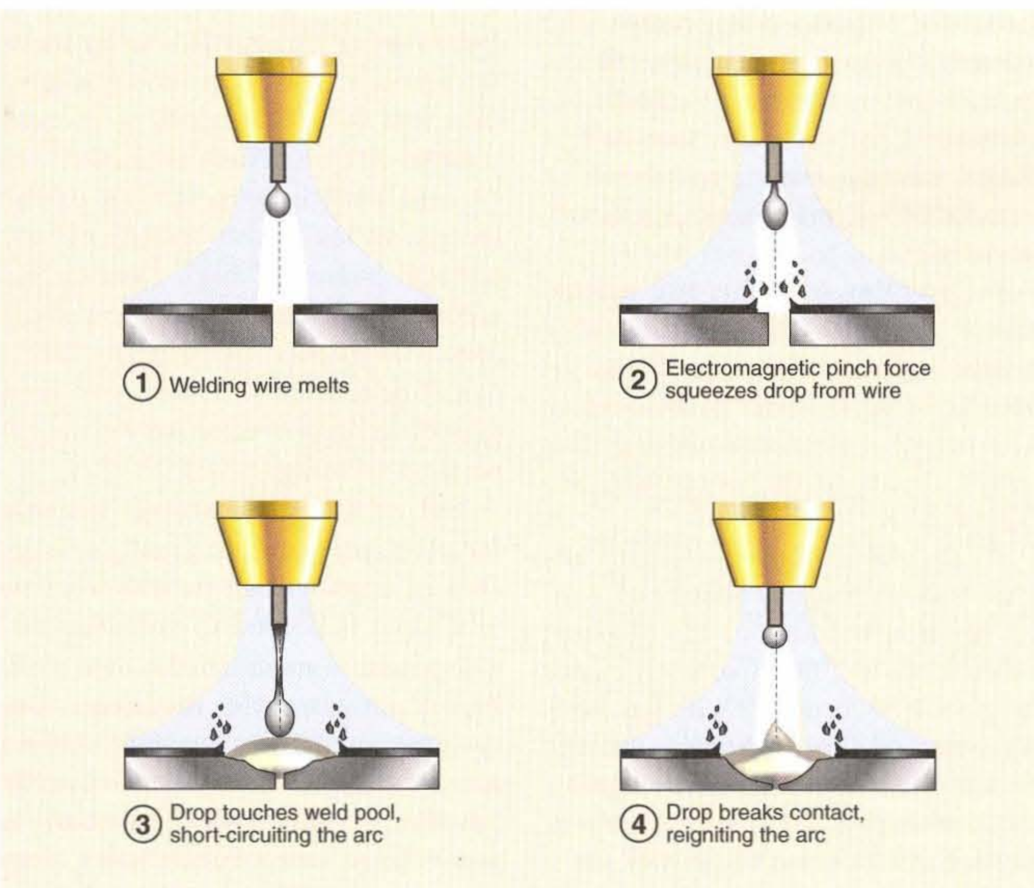


Figure 20-6. *Short circuiting transfer is practical for all welding positions, especially where control of the weld pool is difficult.*

It is particularly appropriate for welding heavy-gauge metal. It is not practical for welding light-gauge metal because it results in melt-through.

Using a longer stickout with spray transfer allows for higher deposition rates. The welding wire has a longer preheat time before entering the arc so there is less amperage needed to melt the wire, and faster travel speeds are possible. If stickout is excessive, reduced penetration may occur. Travel speed and penetration rates must be monitored to ensure that proper penetration is taking place.

Globular Transfer

Globular transfer is the transfer of molten metal in large droplets from the welding wire to the workpiece across an arc. Globular transfer occurs when the welding current is low or is below the transition current. The transition current range extends from the minimum value where the heat melts the welding wire to the point where the high current value induces spray transfer. Only a few drops are transferred per second at low current values, whereas many small drops are transferred when high current values are used.

In globular transfer, the molten ball at the tip of the welding wire grows until its diameter is two or three times the diameter of the welding wire before it separates and transfers across the arc to the workpiece. See Figure 20-8.

As the globule moves across the arc, it assumes an irregular shape and a rotary motion because of the physical forces of the arc. This frequently causes the globule to reconnect with the welding wire and the workpiece, causing the arc to extinguish and then reignite. The result is poor arc stability, poor penetration, and excessive spatter. As a result, globular transfer is not very effective for most GMAW operations. Its use is generally restricted to where low heat input is desired and to welding thin sections of metal.

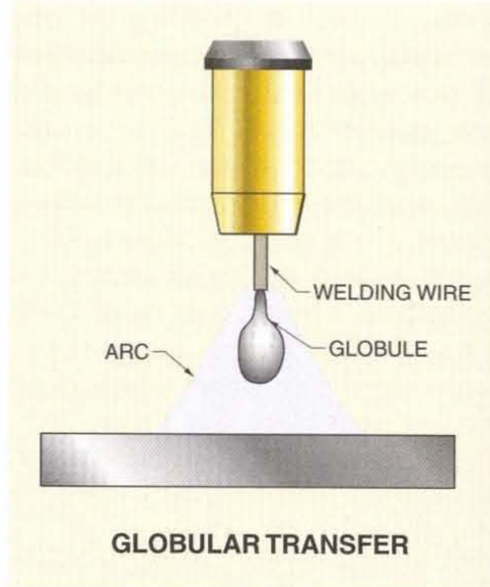


Figure 20-8. *In globular transfer, the molten drop grows to two or three times the diameter of the welding wire before separating and transferring to the workpiece.*

Pulsed Spray Transfer

Pulsed spray transfer is a spray transfer mode in which current is cycled from low to high, at which point spray transfer occurs. High level welding current ensures penetration of the metal and low level welding current permits pulses of high current. No metal transfer occurs at the low level. Metal transfer is produced by directional force that is stronger than gravity, making it effective for out-of-position welding.

Pulsed spray transfer is suitable for all-position welding and is desirable in applications in which a low heat input is needed to minimize distortion and to maintain the weld pool. Pulsed spray transfer requires a special inverter welding machine. Pulsed spray transfer is an extension of spray transfer welding and allows current and voltage levels much lower than those required for continuous spray transfer. A pulsing current typically has

a peak current in the spray transfer current range and a minimum current value in the globular transfer current range.

Current values lower than the transition level are needed when welding under heat transfer conditions that are inadequate for spray transfer.

For example, when performing out-of-position welding, high current results in a weld pool that cannot be retained in position unless the metal being welded has adequate thermal conductivity, and uses the proper joint and plate thickness.

Pulsed spray transfer is achieved by pulsing the current back and forth between the spray transfer and globular transfer current ranges. See Figure 20-9. For example, welding machine A puts out a current in the globular transfer range and welding machine B puts out a current in the spray transfer range. The two outputs are combined to produce a simple pulsed output by electrically switching back and forth between the two currents.

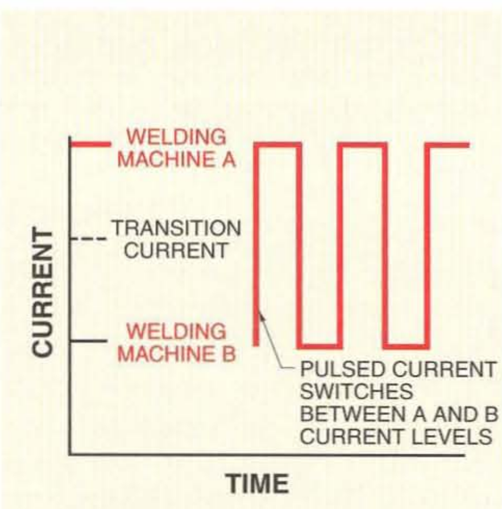


Figure 20-9. *Pulsed spray transfer occurs as the current is pulsed back and forth between the spray transfer and the globular transfer current ranges.*

Transfer only occurs during the spray mode. Globular transfer is suppressed because insufficient time is allowed for globular transfer to occur. Conversely, at the peak current level, spray transfer is ensured by allowing more than sufficient time for transfer to occur.

For the given welding wire deposited by pulsed spray transfer, all the advantages of spray transfer are available at average current levels that range from the minimum level possible with continuous spray transfer down to levels low in the globular transfer range.

Pulsed spray transfer provides many features not previously available with other welding processes:

- The heat input range bridges the gap between and laps over into the heat input ranges available from the spray transfer and short circuiting arc processes. Into its lower heat input range, the pulsed spray transfer process brings the advantages of the continuous spray transfer process. In addition, due to lower heat input, the use of spray transfer is extended greatly into poor heat transfer areas, mainly related to welding out-of-position and on thinner materials.
- The area of overlap with the spray transfer process occurs because a larger diameter electrode, having a higher transition current, leaves the continuous spray and enters the pulsed spray range at a higher current than a smaller electrode. Further, the use of a larger diameter electrode can be continued down to a current value considerably below the transition current associated with using a smaller diameter electrode.
- The pulsed spray transfer process produces a higher ratio of heat input to metal deposition, permits the use of a completely inert gas shield where necessary, and is essentially free from spatter.
- The pulsed spray transfer process is characterized by a uniformity of root penetration that is comparable to GTAW; because of this feature, the process may permit omission of weld backing in some cases.

- The pulsed spray transfer process will not displace the short circuiting transfer process in those areas where the short circuiting transfer process is applicable and more economical.

Pulsed Spray Transfer Welding Machines. The welding machine used for pulsed spray transfer is a constant-voltage machine that combines a standard, 3ϕ, full-wave unit with a 1ϕ, half-wave unit. The 3ϕ unit is the background unit and the 1ϕ unit is the pulsing unit. These units are connected in parallel but commutate (form a unidirectional current) in operation. The waveform of the pulsing current output determines the sequence of metal transfer. See Figure 20-10.

The units are made to switch back and forth in operation by means of the varying output voltage of the pulsing unit. The diode rectifiers in each unit alternately permit or block the passage of current depending upon whether there is a positive or negative voltage difference across their terminals. When the pulse is OFF or its voltage is less than the background voltage, the diode rectifiers of the background unit pass the full value of the instantaneous current. Conversely, when the pulse voltage exceeds the background voltage, blocking the background diode rectifiers, the pulse diode rectifiers pass the full value of the instantaneous current.

Operation of the welding machine for pulsed spray transfer is similar to that of conventional constant-voltage welding machines. The pulse peak voltage is determined by the welding wire type and diameter. The wire feeder is set at a value that produces the required current and is determined by the type and diameter of welding wire. The meters on the welding machine display the average voltage and the average current. See Appendix.

GMAW WELD DISCONTINUITIES

GMAW, like any other form of welding, must be controlled properly to produce consistently high quality welds. Welds should be analyzed to prevent repeated weld defects. Common discontinuities, such as cold lap, porosity, crater cracks, insufficient penetration, excessive penetration, and whiskers, may be encountered when using GMAW.

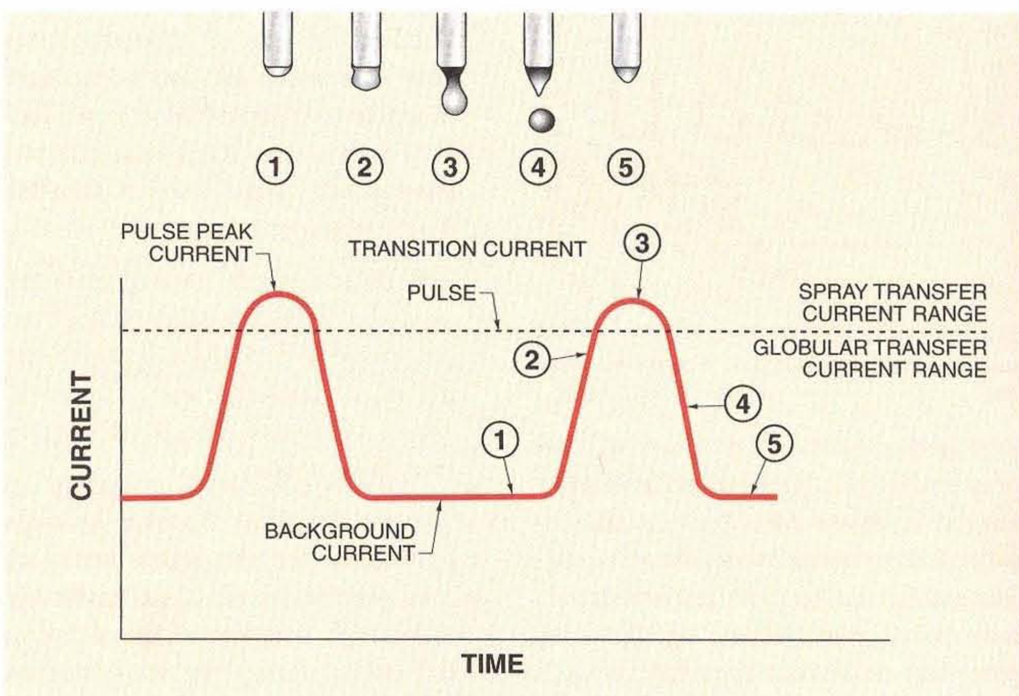


Figure 20-10. *The output current waveform of the pulsed spray transfer welding machine determines the metal transfer sequence.*

Cold Lap

Cold lap usually occurs when the arc does not melt the base metal sufficiently, causing the weld pool to flow into unwelded base metal. See Figure 20-11. Often, if the weld pool is allowed to become too large, cold lap results. For proper fusion, the arc should be kept at the leading edge of the weld pool. Proper arc placement prevents the weld pool from becoming too large and flowing ahead of the welding arc. To prevent cold lap, the size of the weld pool can be reduced by increasing the travel speed or reducing the wire feed speed.

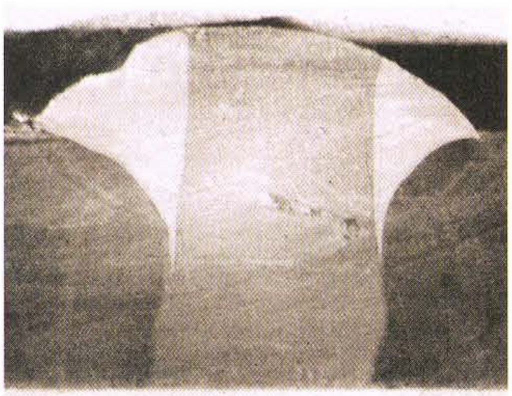


Figure 20-11. *Cold lap occurs when the arc does not melt the base metal sufficiently.*

Porosity

Generally, surface porosity is the direct result of atmospheric contamination. Atmospheric contamination occurs if the shielding gas level is set either too low or too high. If the shielding gas level is too low, the air in the arc area is not fully displaced; if the shielding gas flow is too high, air turbulence is generated which prevents complete shielding. On occasion, porosity occurs if welding is performed in a windy area. Without a protective wind shield the shielding gas envelope may be blown away, exposing the molten weld pool to the contaminating effects of the air. Subsurface porosity is caused by removal of the welding gun and the shielding gas before the weld pool has solidified; moisture in the shielding gas; rust, paint, dirt, or oil on the base metal; or an excessive tip-to-work distance. Although porosity is categorized as surface or subsurface, it can occur throughout the weld area. See Figure 20-12.

Cold lap occurs if the arc does not melt the base metal sufficiently.

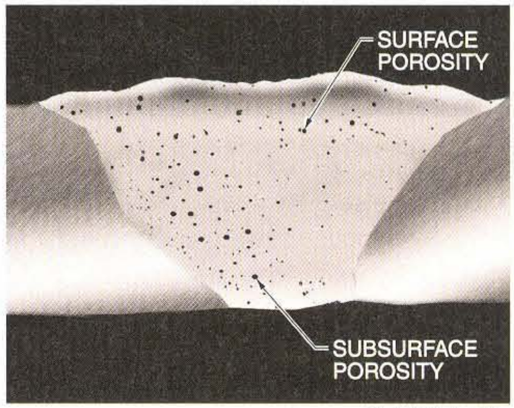


Figure 20-12. *Porosity can occur throughout the weld area and is categorized as surface or subsurface porosity.*

Check the weld for surface porosity. Surface porosity is usually caused by improper gas shielding.

Crater Cracks

The primary cause of crater cracks is removing the welding gun and the shielding gas before the weld pool has solidified. Other possible causes of crater cracks are moisture in the shielding gas; rust, paint, dirt, or oil on the base metal; and excessive tip-to-work distance. See Figure 20-13.

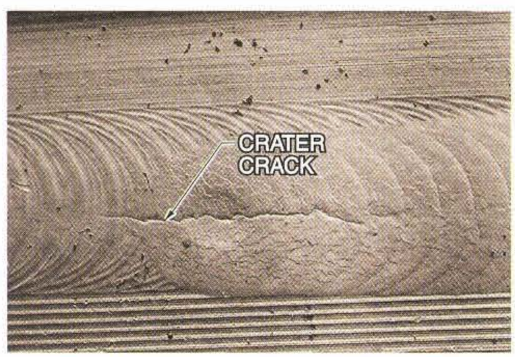
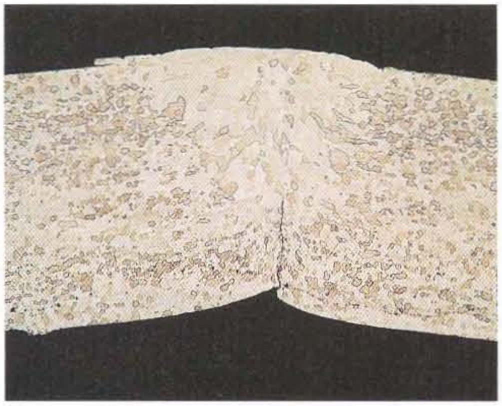


Figure 20-13. *Crater cracks can occur if the welding gun is removed before the weld pool has solidified.*

Lack of Penetration

Lack of penetration (insufficient penetration) is due to a low heat input in the weld area or failure to keep the arc properly located on the leading edge of the weld pool. If the heat input is too low, increase the wire feed speed to achieve a higher current. See Figure 20-14.

Do not remove the welding gun from the weld area until the weld pool has solidified; otherwise, cracks may develop.



Stork-Technimet, Inc.

Figure 20-14. *Lack of penetration can result from low heat input to the weld area or a failure to keep the arc located properly on the leading edge of the weld pool.*

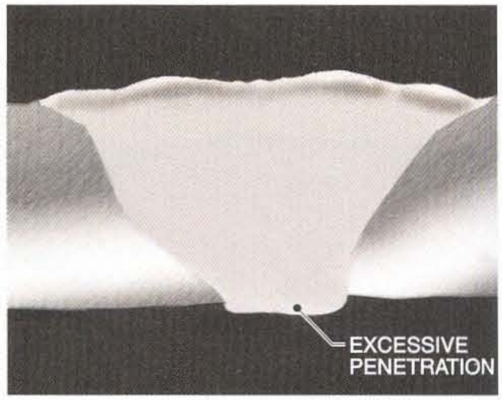
Lack of penetration or excessive penetration is the result of failure to control heat input.

Excessive Penetration

Excessive penetration (melt-through) is caused by excessive heat in the weld zone. Excessive penetration results in a weld bead that protrudes below the bottom of the joint. See Figure 20-15. Reducing the wire feed speed lowers the current and less heat is generated, eliminating excessive penetration. Excessive penetration can also be prevented by increasing the travel speed. If the root opening in the joint is too wide, melt-through may result. A wide root opening can be compensated for by increasing stickout and weaving the welding gun.

Whiskers

Whiskers are short lengths of electrode wire sticking through the weld joint. Whiskers are caused by pushing the wire past the leading edge of the weld pool. A small section of wire protrudes inside the joint and becomes welded to the deposited metal. To remedy this defect, reduce the travel speed, increase the tip-to-work distance slightly, or reduce the wire feed speed.



Stork Technimet, Inc.

Figure 20-15. *Reducing the wire feed speed and increasing the travel speed can prevent excessive penetration.*

POINTS TO REMEMBER

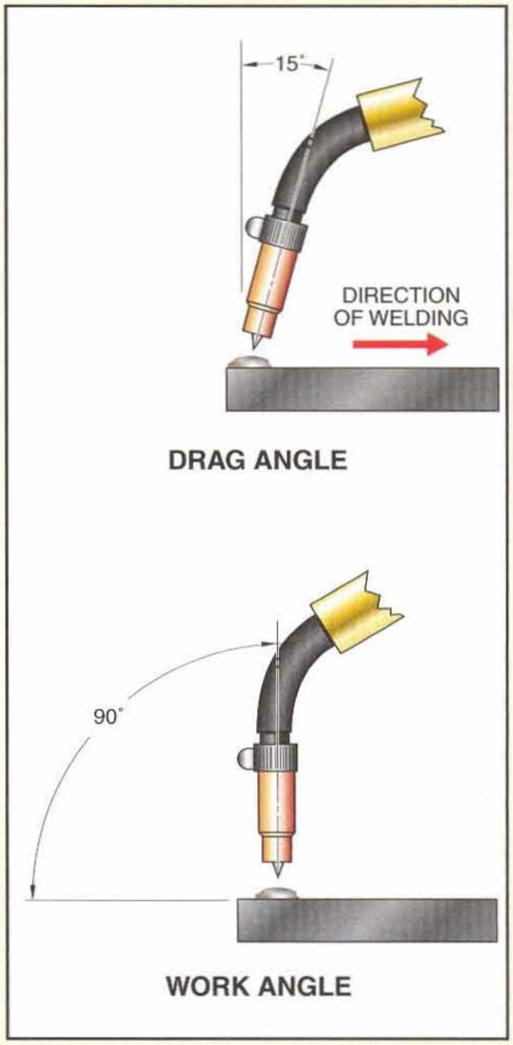
1. GMAW is a faster welding process than SMAW and is easy to learn.
2. Groove joints used with GMAW have smaller root faces, smaller root openings, and a narrower included angle, all of which reduce the joint area to require less weld metal.
3. Keep the welding gun properly positioned to ensure a uniform weld with proper penetration.
4. Ensure that the contact tube and gas nozzle orifices are clean to prevent clogging, which restricts wire feed and shielding gas flow.
5. Do not remove the welding gun from the weld area until the weld pool has solidified. The shielding gas prevents cracks from developing in the molten weld pool.
6. Short circuiting transfer welding is best for welding light-gauge metals.
7. High current is used with spray transfer to produce a steady, quiet arc with a well-defined core within which metal transfer takes place.
8. Cold lap occurs if the arc does not melt the base metal sufficiently.
9. Check the weld for surface porosity. Surface porosity is usually caused by improper gas shielding.
10. Do not remove the welding gun from the weld area until the weld pool has solidified; otherwise, cracks may develop.
11. Lack of penetration or excessive penetration is the result of failure to control heat input.

Exercises

Depositing Beads on Mild Steel in Flat Position

exercise 1

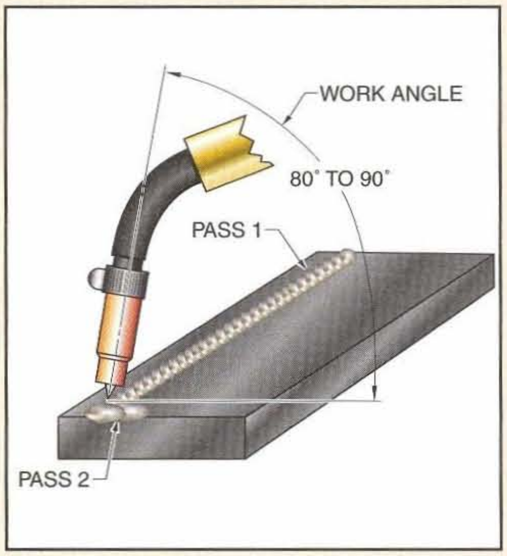
1. Obtain a .035″, E-70S-3 welding wire.
2. Insert the welding wire in the welding gun and set wire stickout to 1/4″ to 3/8″.
3. Set the welding machine output for DCEP.
4. Set the current at 100 A to 120 A; set voltage at 19 V to 21 V.
5. Set the shielding gas (carbon dioxide) at 20 cfh.
6. Obtain a piece of mild steel 3/16″ to 1/4″ thick and 4″ to 6″ long.
7. Position the workpiece in flat position.
8. Set the wire feed control so that the ammeter reads between 100 A and 120 A. To obtain the correct reading, have another person observe the current while welding is being performed.
9. Set the voltage to 26 V to 28 V using the same procedure.
10. Position the welding gun at a 90° work angle and a 10° to 15° drag angle.
11. Adjust the voltage until wire feeds properly and the bead is 5/16″ wide and 1/8″ high.
12. Deposit a series of straight, consistent beads approximately 3/8″ apart.



Depositing Buildup on Mild Steel in Flat Position

exercise 2

1. Complete equipment setup and adjustment as in Exercise 1.
2. Obtain a piece of mild steel 1/4″ thick and 4″ to 6″ long.
3. Position the workpiece in flat position.
4. Position the welding gun at a 90° work angle and a 10° to 15° drag angle to deposit a bead 1/4″ from the edge of the workpiece. The bead should be 5/16″ wide and 1/8″ high.
5. Deposit a second bead overlapping the first by half. Use an 80° to 90° work angle and a 10° to 15° drag angle.
6. Deposit consistent, overlapping beads until the workpiece is covered.



Welding a Butt Joint on Mild Steel in Flat Position

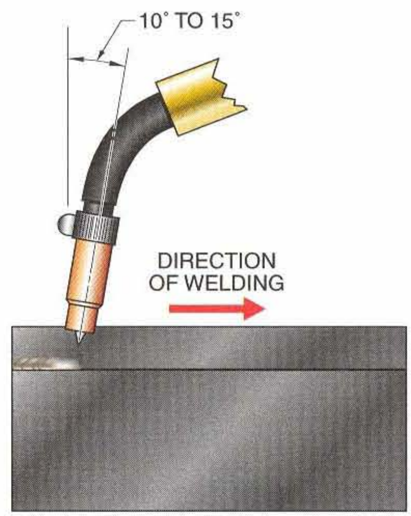
exercise 3

1. Complete equipment setup and adjustment as in Exercise 1.
2. Obtain two pieces of mild steel 3/16″ to 1/4″ thick, 1½″ wide, and 6″ long.
3. Form a butt joint, with a 3/32″ to 1/8″ root opening, and tack weld.
4. Position the workpiece so the weld joint is in flat position.
5. Position the welding gun at a 90° work angle and a 10° drag angle.
6. Use a slight weaving motion to control the weld pool and a travel speed that allows for complete penetration.
7. Maintain the electrode on the leading edge of the weld pool to prevent whiskers.
8. If excessive penetration occurs, lengthen the electrode extension, decrease the current, and/or adjust the voltage for a smooth arc.

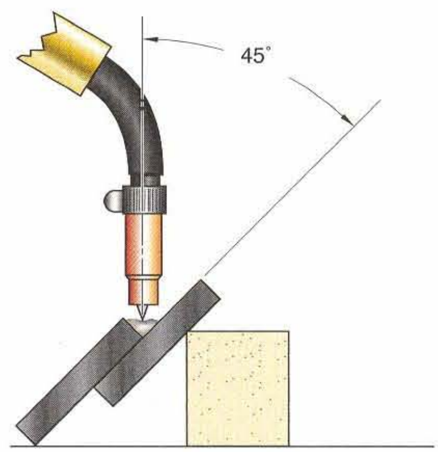
Welding a Lap Joint on Mild Steel in Flat Position

exercise 4

1. Complete equipment setup and adjustment as in Exercise 1.
2. Obtain two pieces of mild steel 3⁄16″ to 1⁄4″ thick, 1½″ wide, and 6″ long.
3. Form a lap joint and tack together.
4. Position the workpiece so the weld joint is in flat position.
5. Position the welding gun at a 45° work angle and a 10° to 15° drag angle. Use a slight weaving motion.
6. The bead face should be flat to slightly convex.



DRAG ANGLE

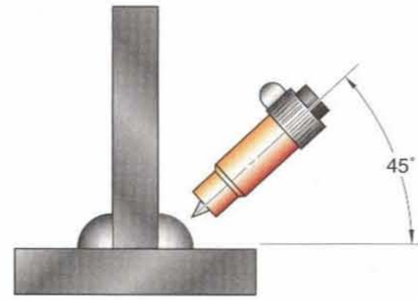


WORK ANGLE

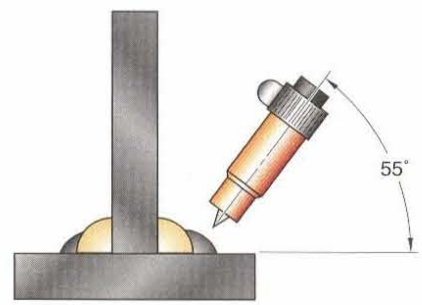
Welding a Multiple-Pass T-Joint on Mild Steel in Horizontal Position

exercise 5

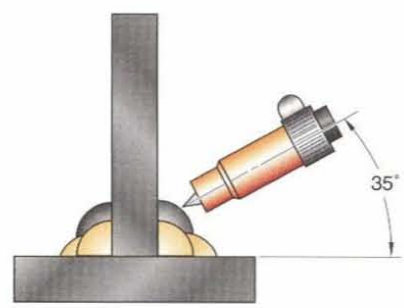
1. Complete equipment setup and adjustment as in Exercise 1.
2. Obtain two pieces of mild steel 3/16″ to 1/4″ thick, 1½″ wide, and 6″ long.
3. Form a T-joint with the pieces at a 90° angle and tack together.
4. Position the workpiece so the weld joint is in horizontal position.
5. Position the welding gun at a 45° work angle and a 10° to 15° drag angle. Deposit the first pass on both sides of the T-joint.
6. Position the welding gun at a 55° work angle and a 10° to 15° drag angle. Deposit the second pass on both sides of the T-joint overlapping the first pass by half.
7. Position the welding gun at a 35° work angle and a 10° to 15° drag angle. Deposit the third pass on both sides of the T-joint overlapping the first and second passes.



Pass 1



Pass 2



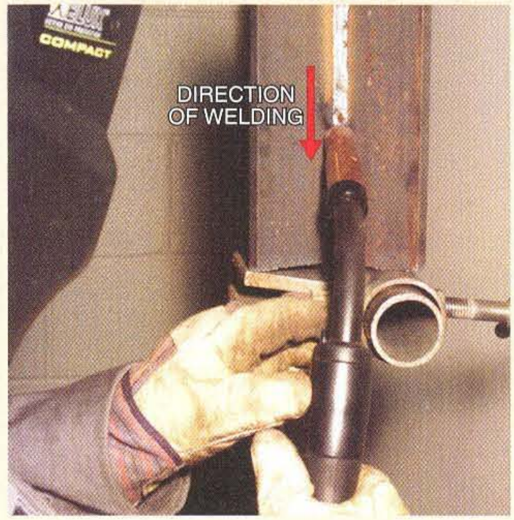
Pass 3

WORK ANGLE

Welding a T-Joint on Mild Steel in Vertical Position

exercise 6

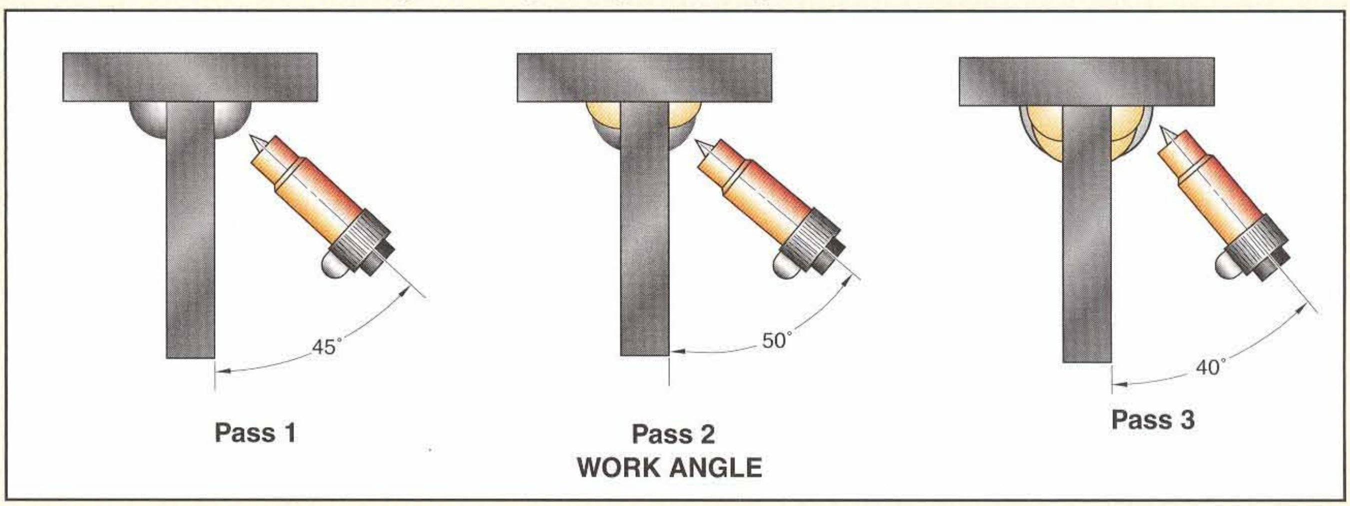
1. Complete equipment setup and adjustment as in Exercise 1.
2. Obtain two pieces of mild steel 3⁄16″ to 1⁄4″ thick, 2″ wide, and 6″ long.
3. Form a T-joint with the pieces at a 90° angle and tack together.
4. Position the workpiece so the weld joint is in vertical position.
5. Position the welding gun at a 45° work angle and a 10° to 20° drag angle.
6. Weld downhill using a slight weaving motion. Pause at the toes of the weld to prevent undercutting.



Welding a T-Joint on Mild Steel in Overhead Position

exercise 7

1. Complete equipment setup and adjustment as in Exercise 1.
2. Obtain two pieces of mild steel 3⁄16″ to 1⁄4″ thick, 2″ wide, and 6″ long.
3. Form a T-joint with the pieces at a 90° angle and tack together.
4. Position the workpiece so the weld joint is in overhead position.
5. Position the welding gun at a 45° work angle and a 5° to 10° drag angle. Deposit the first pass on both sides of the T-joint.
6. Position the welding gun at a 50° work angle and a 5° to 10° drag angle. Deposit the second pass on both sides of the T-joint using a slight weaving motion.
7. Position the welding gun at a 40° work angle and a 5° to 10° drag angle. Deposit the third pass on both sides of the T-joint using a slight weaving motion.



Welding Joints on Aluminum

exercise 8

1. Obtain two pieces of aluminum, $\frac{3}{16}''$ to $\frac{1}{4}''$ thick, 2″ wide, and 6″ long.
2. Form the proper joint and tack together.
3. Position the workpiece so the weld joint is in proper position.
4. Set voltage, wire feed speed, and shielding gas flow. See Appendix.
5. Angle the welding gun to a 15° drag angle with a wire stickout of $\frac{1}{2}''$ to $\frac{3}{4}''$.
6. Use the pushing technique. Use the procedures for welding mild steel to complete a butt joint, a lap joint, and a T-joint on aluminum.

QUESTIONS FOR STUDY AND DISCUSSION

1. How does GMAW differ from GTAW?
2. At what work angle should the welding gun be held for horizontal fillet welding?
3. At what work angle should the welding gun be held for flat fillet welding?
4. What determines whether a pulling or pushing technique should be used?
5. What is the difference between spray transfer and globular transfer?
6. Why is globular transfer ineffective for welding heavy-gauge metals?
7. What is meant by short circuiting transfer? For what type of welding is this most effective?
8. What is the probable cause for the formation of cold laps in a weld?
9. What should be done to prevent surface porosity in a weld?
10. How can crater porosity or cracks be prevented?
11. What should be done if weld penetration is insufficient?

GMAW - Applications

21

Gas Metal Arc Welding (GMAW)

GMAW has become an accepted process for joining all types of metals. Production welding can be easily mechanized with GMAW, substantially reducing manufacturing costs. Generally, the same type of equipment and welding techniques apply to all metals when welding with GMAW.

GMAW can be used to weld carbon steel, aluminum, stainless steel, and copper. Welding parameters such as edge preparation, electrode diameter, shielding gas flow rate, proper current, and electrode feed speed are set based on weld requirements.

CARBON STEEL

Carbon steels can be welded using short circuiting transfer and spray transfer. Edge preparation and joint design requirements vary depending on the thickness of the carbon steel.

Steel from .035″ to 1/8″ thick can be butt welded with no edge preparation. When welding a square butt joint on thin steel, a root opening of 1/16″ or less is recommended. For wider openings, short circuiting transfer should be used because relatively large gaps at the root opening are more easily bridged without excessive penetration.

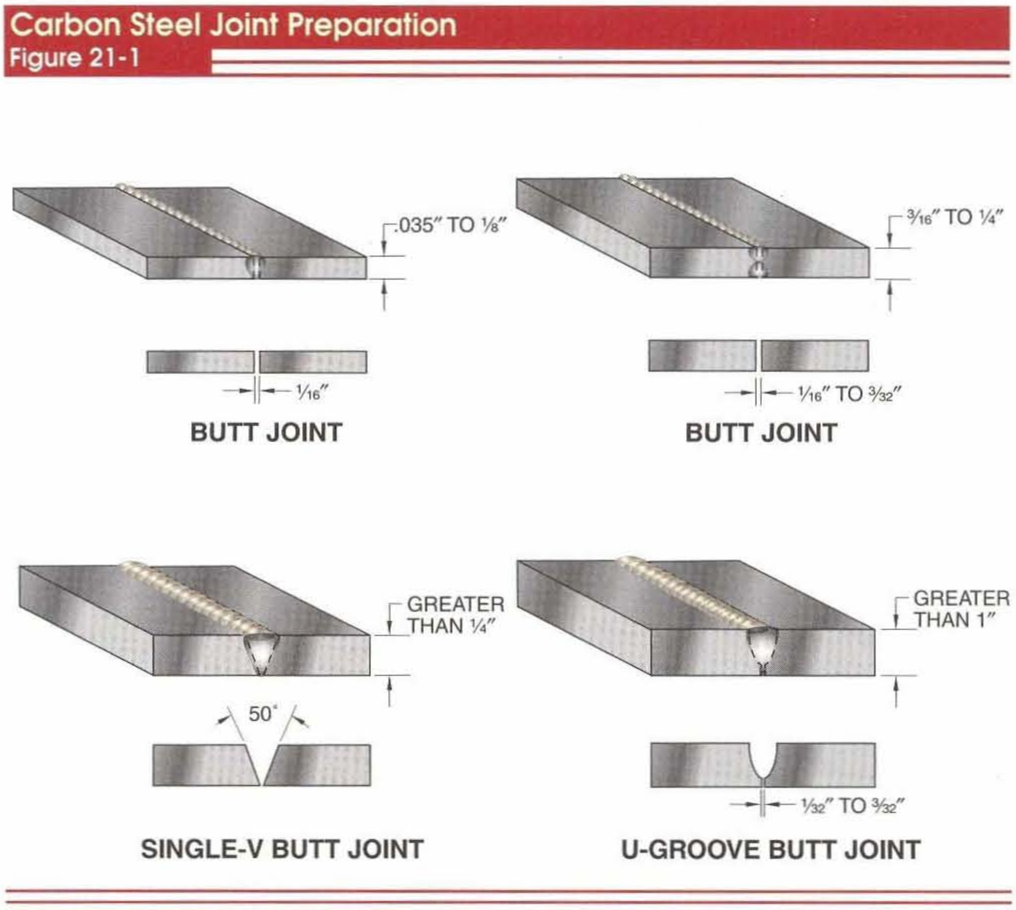
A butt joint with no edge preparation and a 1/16″ to 3/32″ root opening may be used for carbon steel 3/16″ to 1/4″ thick. Two passes are generally required to ensure complete penetration and to fill the joint.

Beveling is required on steel more than 1/4″ thick. A single-V or double-V bevel with a 50° to 60° groove angle is used for carbon steel up to 1″ thick. A U-groove with a root opening of 1/32″ to 3/32″ is necessary on carbon steel thicker than 1″. See Figure 21-1. The sequence of bead deposits for multiple pass welds is similar to SMAW.

Shielding gases used with GMAW are straight CO_2 or an Ar/CO_2 mixture. For short circuiting transfer on carbon steels and low-alloy steels, a 75% Ar/25% CO_2 mixture is preferred. The Ar/CO_2 mixture improves arc stability and minimizes spatter. A mixture of Argon and 5% to 10% CO_2 may also be used, and results in deeper penetration with faster welding speeds.

Carbon steel welding with spray transfer can be performed using a 95% to 98% Ar/2% to 5% O_2 mixture. Adding oxygen to the shielding gas mixture provides a more stable arc, minimizes undercutting, and permits faster travel speeds. Straight CO_2 may be used for high-speed production welding; however, straight CO_2 does not provide a true spray transfer, but has characteristics similar to globular transfer. Straight CO_2 is typically used for globular transfer, allowing high productivity rates.

Figure 21-1. *Proper edge preparation and root opening are necessary when welding carbon steel butt joints using GMAW.*



Welding parameters are set based on the thickness of the metal used.

Welding parameters such as electrode diameter, proper current and voltage, wire feed speed, and shielding gas flow are set based on the carbon steel thickness. See Figure 21-2.

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In the GMAW process, a consumable wire electrode is fed into a weld pool that is protected by a shielding gas that completely covers the weld pool.

ALUMINUM

Joint design for aluminum is similar to that for steel. However, a narrower root opening and lower welding current are recommended due to the higher fluidity of the metal. Generally, aluminum 1/8″ thick or more can be welded using GMAW. However, some welders may be able to weld thinner sections.

Argon gas is the preferred shielding gas for GMAW on aluminum up to 1″ thick because it provides better metal transfer and arc stability with less spatter. In flat position welding of 1100 and 3003 aluminum, the addition of a small amount of oxygen to the argon increases spray transfer and improves coalescence (flow of metals together). When welding aluminum between 1″ and 2″ thick, a mixture of 90% Ar/10% He provides the higher heat input possible with helium and the good cleaning action obtained with argon.

GMAW — CARBON STEEL (SHORT CIRCUITING TRANSFER)						
Metal Thickness*	Electrode Diameter*	DCEP Welding Current†	DCEP Arc Voltage‡	Wire Feed Speed§	Travel Speed§	Shielding Gas Flow‖
.025	.030	30 – 50	15 – 17	85 – 100	12 – 20	15 – 20
.031	.030	40 – 60	15 – 17	90 – 130	18 – 22	15 – 20
.037	.035	55 – 85	15 – 17	70 – 120	35 – 40	15 – 20
.050	.035	70 – 100	16 – 19	100 – 160	35 – 40	15 – 20
.063	.035	80 – 110	17 – 20	120 – 180	30 – 35	20 – 25
.078	.035	100 – 130	18 – 20	160 – 220	25 – 30	20 – 25
.125	.035	120 – 160	19 – 22	210 – 290	20 – 25	20 – 25
.125	.045	180 – 200	20 – 24	210 – 240	27 – 32	20 – 25
.187	.035	140 – 160	19 – 22	210 – 290	14 – 19	20 – 25
.187	.045	180 – 205	20 – 24	210 – 245	18 – 22	20 – 25
.250	.035	140 – 160	19 – 22	240 – 290	11 – 15	20 – 25
.250	.045	180 – 225	20 – 24	210 – 290	12 – 18	20 – 25

* in in.
† in amps
‡ in volts
§ in inches per minute (ipm)
‖ in cfh

Figure 21-2. *Welding parameters should be set based on carbon steel thickness.*

Using short circuiting transfer on aluminum produces a colder arc than is produced with spray transfer, permitting the weld pool to solidify rapidly. This action is especially useful for vertical, overhead, and horizontal welding, and for welding thin aluminum. When using GMAW in vertical position, a downhill technique is preferred. Welding parameters such as edge preparation, electrode diameter, argon flow, proper current and voltage, and electrode feed speed for short circuiting transfer should be set based on aluminum thickness. See Figure 21-3.

Spray transfer on aluminum is especially suitable for thick sections. With spray transfer, more heat is produced to melt the electrode and the base metal. Vertical, horizontal, and overhead welds are typically more difficult with spray transfer than with short circuiting transfer. Welding parameters such as edge preparation, electrode diameter, argon flow, proper current and voltage, and electrode feed speed for spray transfer should be set based on aluminum thickness. See Figure 21-4.

Argon gas is the preferred shielding gas for GMAW on aluminum up to 1″ thick because it provides better metal transfer and arc stability with less spatter.

STAINLESS STEEL

Stainless steel was initially developed to prevent rusting and corrosion that occured with carbon steel. Stainless steel is produced to a higher quality level than carbon steels and has fewer impurities, making it a reliable material for welding. On stainless steel ¼″ thick or more, the welding gun should be moved back-and-forth with a slight side-to-side movement.

GMAW — ALUMINUM (SHORT CIRCUITING TRANSFER)						
Metal Thickness*	Edge Preparation	Electrode Diameter*	Argon Flow†	DCEP Current‡	Voltage§	Electrode Feed Speed‖
.040	Fillet or tight Butt	.030	30	40	15	240
.050	Fillet or tight Butt	.030	15	50	15	290
.063	Fillet or tight Butt	.030	15	60	15	340
.093	Fillet or tight Butt	.030	15	90	15	410

* in in.
† in cfh
‡ in amps
§ in volts
‖ in ipm (approximate)

Figure 21-3. *Welding parameters for short circuiting transfer on thin aluminum should be set based on aluminum thickness.*

GMAW — ALUMINUM (SPRAY TRANSFER)					
Metal Thickness*	Edge Preparation	Electrode Diameter*	Argon Flow†	DCEP Current‡	Voltage§
.250	Single-V butt (60° groove angle) sharp root face use backing bar	3/64	35	180	24
	Square butt with backing bar	3/64	40	250	26
	Square butt with no backing bar	3/64	35	220	24
.375	Single-V butt (60° groove angle) sharp root face use backing bar	1/16	40	280	27
	Double-V butt (75° groove angle 1/16″ root face). No backing bar. Back chip after root pass	1/16	40	260	26
	Square butt with no backing bar	1/16	50	270	26
.500	Single-V butt (60° groove angle) sharp root face use backing bar	1/16	50	310	27
	Double-V butt (75° groove angle 1/16″ root face). No backing bar. Back chip after root pass	1/16	50	300	27

* in in.
† in cfh
‡ in amps
§ in volts

Figure 21-4. *Welding parameters for spray transfer on thick aluminum should be set based on aluminum thickness.*

Thin stainless steel is best welded with a slight back-and-forth motion along the joint. See Figure 21-5. The forehand technique is generally used for welding stainless steel.

GMAW Weaving Motions
Figure 21-5

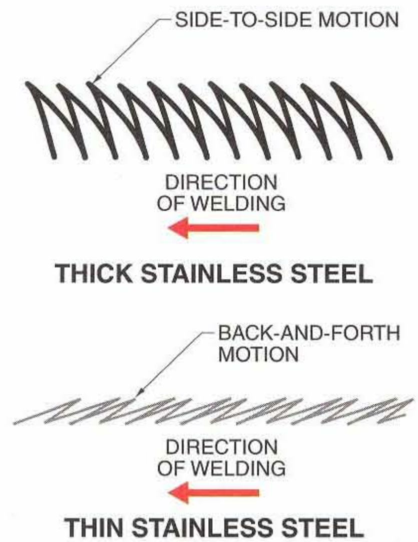


Figure 21-5. *When using GMAW to weld stainless steel plates, a slight weaving motion is used.*

Many of the characteristics of stainless steel, such as its corrosion resistance, sensitivity to heat, and low thermal and electrical conductivity, can be controlled once a welder understands how welding affects these characteristics. Properly identifying the type of stainless steel and its particular characteristics is necessary to determine which characteristics to control during welding. When using GMAW on stainless steels, proper ventilation is necessary due to the fumes given off by the metal.

Short circuiting transfer can be used on thin stainless steel in overhead or vertical position. Welding parameters such as edge preparation, electrode diameter, shielding gas flow, proper current and voltage, electrode feed speed, welding speed, and welding passes for short circuiting transfer should be set based on stainless steel thickness. See Figure 21-6.

Quality welds can be produced on stainless steel using the spray transfer process with a 1/16″ diameter electrode and high current. DCEP with Argon and 1% to 2% O_2 may be used for spray transfer on stainless steel. Welding parameters such as edge preparation, electrode diameter, shielding gas flow, proper current, electrode feed speed, welding speed, and welding passes for spray transfer should be set based on stainless steel thickness. See Figure 21-7.

Copper backing bars should be used when welding stainless steel up to 1/16″ thick. Precautions must be taken to prevent air from reaching the underside of the weld while the weld pool is solidifying because oxygen and nitrogen in the air will embrittle the weld. To prevent air from contacting the underside of the weld, an argon back-up gas is often used.

When using GMAW on stainless steels, proper ventilation is necessary to remove the fumes emitted.

COPPER

Using GMAW on copper is usually restricted to the deoxidized types of copper. Welding electrolytic copper is not advisable because of the potential for embrittlement exhibited by such welds.

Argon is preferred as the shielding gas for thin copper. For copper 1″ thick or more, a mixture of 65% He/35% Ar is recommended.

Steel backing bars are required for welding copper 1/8″ thick or less. Preheating is not necessary for copper 1/8″ thick or less. Preheating at 400°F (204°C) is advisable on sections 3/8″ thick or more. Welding parameters such as edge preparation, electrode diameter, proper current and voltage, electrode feed speed, and welding speed should be set based on copper thickness. See Figure 21-8.

Steel backing bars are required for welding copper 1/8″ thick or less.

Filler metals that can be used to weld copper are specified in ANSI/AWS A5.6, Specifications for Covered Copper and Copper Alloy Arc Welding Electrodes.

Preheating copper at 400°F (204°C) is advisable on sections 3/8″ thick or more.

GMAW — STAINLESS STEEL (SHORT CIRCUITING TRANSFER)								
Metal Thickness*	Edge Preparation	Electrode Diameter*	Gas Flow†	DCEP Current‡	Voltage§	Electrode Feed Speed‖	Welding Speed‖	Welding Passes
.063	Non-positioned fillet or lap	.030	12 – 30	85	15	184	18	1
.063	Square Butt	.030	12 – 30	85	15	184	20	1
.078	Non-positioned fillet or lap	.030	12 – 30	90	15	192	14	1
.078	Square Butt	.030	12 – 30	90	15	192	12	1
.093	Non-positioned fillet or lap	.030	12 – 30	105	17	232	15	1
.125	Non-positioned fillet or lap	.030	12 – 30	125	17	280	16	1

* in in.
† CO_2 in cfh
‡ in amps
§ in volts
‖ in ipm

Figure 21-6. *Welding parameters for short circuiting transfer on stainless steel should be set based on stainless steel thickness.*

GMAW — STAINLESS STEEL (SPRAY TRANSFER)								
Metal Thickness*	Edge Preparation	Electrode Diameter*	Gas Flow	DCEP Current‡	Voltage§	Electrode Feed Speed‖	Welding Speed‖	Welding Passes
.125	Square butt with backing	1⁄16	35†	200 – 250	24	110 – 150	20	1
.250	Single-V butt (60° groove angle) no root face	1⁄16	35†	250 – 300	25 – 26	150 – 200	15	2
.375	Single-V butt (60° groove angle) 1⁄16″ root face	1⁄16	(1%-O_2)	275 – 325	25 – 26	225 – 250	20	2
.500	Single-V butt (60° groove angle) 1⁄16″ root face	3⁄32	(1%-O_2)	300 – 350	26 – 27	75 – 85	5	3 – 4
.750	Single-V butt (90° groove angle) 1⁄16″ root face	3⁄32	(1%-O_2)	350 – 375	25 – 27	85 – 95	4	5 – 6
1.000	Single-V butt (90° groove angle) 1⁄16″ root face	3⁄32	(1%-O_2)	350 – 375	25 – 27	85 – 95	2	7 – 8

* in in.
† in cfh
‡ in amps
§ in volts
‖ ipm

Figure 21-7. *Welding parameters for spray transfer on stainless steel should be set based on stainless steel thickness.*

GMAW — COPPER						
Metal Thickness*	Edge Preparation	Electrode Diameter*	DCEP Current†	Voltage‡	Electrode Feed Speed§	Welding Speed§
1/8	Square Butt, with steel backing bar	1/16	310	27	200	30
1/4	Square Butt	3/32	460	26	135	20
1/4	Square Butt	3/32	500	26	150	20
3/8	Double bevel, 90° groove angle, 3/16″ root face	3/32	500	27	150	14
3/8	Double bevel, 90° groove angle, 3/16″ root face	3/32	550	27	170	14
1/2	Double bevel, 90° groove angle, 1/4″ root face	3/32	540	27	165	12
1/2	Double bevel, 90° groove angle, 1/4″ root face	3/32	600	27	180	10

* in in.
† in amps
‡ in volts
§ in ipm

Figure 21-8. *Welding parameters should be set based on copper thickness.*

POINTS TO REMEMBER

1. Welding parameters are set based on the thickness of the metal used.
2. Argon gas is the preferred shielding gas for GMAW on aluminum up to 1″ thick because it provides better metal transfer and arc stability with less spatter.
3. When using GMAW on stainless steels, proper ventilation is necessary to remove the fumes emitted.
4. Steel backing bars are required for welding copper 1/8″ thick or less.
5. Preheating copper at 400°F (204°C) is advisable on sections 3/8″ thick or more.

QUESTIONS FOR STUDY AND DISCUSSION

1. When welding carbon steels, what thickness range may be butt welded with no edge preparation?
2. What type of joint is required for carbon steel greater than 1″ thick?
3. What shielding gas mixture is recommended for welding carbon steels?
4. Why is spray transfer preferred for welding thick sections of aluminum?
5. Which technique should be used for GMAW in vertical position?
6. What type of backing is required when welding stainless steel?
7. What type of backing is required when welding copper?
8. When should preheating be used on copper?

22 Flux Cored Arc Welding (FCAW)

The flux cored arc welding (FCAW) process was developed in the 1950s. It is an arc welding process similar to GMAW in that it uses a continuously fed electrode. FCAW has become more commonly used as a result of developments and improvements in welding machines, wire feed systems, and fluxes. Welding guns equipped with fume extractors have also improved FCAW welding conditions. FCAW can be used to weld carbon steels, low-alloy steels, various stainless steels, and some cast irons.

Self-shielded flux cored arc welding (FCAW-S) is a variation of FCAW in which the shielding gas is provided solely by the flux material within the electrode. FCAW-S is commonly used on medium thicknesses of metal and can be used for all-position welding. Gas-shielded flux cored arc welding (FCAW-G) is an FCAW variation that produces high-quality welds at a lower cost and with less effort than SMAW. FCAW-G generally produces a deeper penetrating weld than FCAW-S.

FLUX CORED ARC WELDING (FCAW)

Flux cored arc welding (FCAW) is an arc welding process that uses a tubular electrode with flux in its core. FCAW is very similar to GMAW in principle of operation and equipment used. In FCAW, weld metal is transferred as in GMAW globular or spray transfer. However, FCAW can achieve greater weld metal deposition and deeper penetration than GMAW short circuiting transfer.

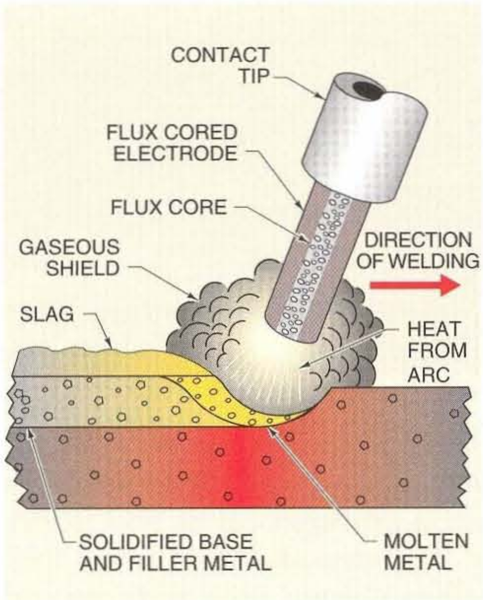
The flux cored arc welding process was developed in the 1950s with the development of an "inside-out" electrode that contained a core of flux material. However, even with the flux cored electrode, an external shielding gas was required. In 1959, a flux cored electrode was developed that did not require an external shielding gas. Shielding gas could be generated solely by the flux contained in the core of the electrode consumed during the welding process. This reduced the cost of the welding process by eliminating the need for additional shielding gas and its accompanying equipment. Shielding gas is used in the FCAW-G process for increased penetration and filler metal deposition.

The two variations for applying FCAW are self-shielded flux cored arc welding (FCAW-S) and gas-shielded flux cored arc welding (FCAW-G).

Self-shielded flux cored arc welding (FCAW-S) is an FCAW variation in which shielding gas is provided exclusively by the flux core within the electrode core. The heat of the welding arc causes the flux to melt, creating a gaseous shield around the arc and the weld pool. See Figure 22-1. FCAW-S is also called Innershield® in the field. Innershield® is a flux cored arc welding process developed by the Lincoln Electric Manufacturing Company.

Self-shielded flux cored arc welding (FCAW-S) is an FCAW variation in which shielding gas is provided exclusively by the flux within the electrode.

Figure 22-1. *In FCAW-S, a tubular electrode containing flux ingredients is used to produce a gaseous shield around the weld pool.*



Gas-shielded flux cored arc welding (FCAW-G) is an FCAW variation in which the shielding is obtained from both the CO_2 gas flowing from the gas nozzle and from the flux core of the electrode.

Gas-shielded flux cored arc welding (FCAW-G) is an FCAW variation in which the shielding is obtained from both the CO_2 gas flowing from the gas nozzle and from the flux core of the electrode. FCAW-G is commonly performed in flat or horizontal position. With small-diameter electrodes, vertical or overhead welding may be possible.

Advantages of FCAW

FCAW produces a quality weld at lower cost with less effort than SMAW, and is more flexible than SAW.

The FCAW process combines the best qualities of SMAW, SAW, and GMAW. FCAW uses flux agents that dissolve oxides and remove detrimental materials from the weld area. The FCAW process provides the welder with the capability to weld continuously for long periods. FCAW produces a quality weld with less effort than SMAW, and is more flexible than SAW. Some additional benefits of FCAW include the following:

- requires less precleaning than GMAW
- produces less distortion than SMAW
- produces smooth, uniform beads with an excellent weld appearance
- has a high deposition rate
- is capable of relatively high travel speeds
- welds a variety of steels and a wide range of metal thicknesses

FCAW EQUIPMENT

Equipment for FCAW is similar to that used for GMAW. A welding machine, welding gun, wire feeder, and flux cored electrode are required. Additionally, for FCAW-G, shielding gas and a shielding gas supply system are required.

The welding equipment can be designed for semiautomatic or mechanized operation. With semiautomatic equipment, the welder moves a handheld welding gun along the weld joint. With mechanized equipment, the operator makes equipment adjustments as required while observing the welding operation. See Figure 22-2.

Some FCAW wires give off fluorides which can burn the skin and irritate the nostrils and eyes. Respiratory equipment must be used. Standard shop ventilation systems may not be capable of eliminating the smoke produced by FCAW welding. A fume extraction system is used to protect workers and to remove smoke from the work area. A fume extractor may be attached to a flexible hose arm that can be moved near the work area or to a separate ventilation system within the shop. See Figure 22-3. Where smoke and fumes are not a problem for other workers, the welder may use a personal ventilation system to protect against fumes.

Specially designed welding guns are also available that have a built-in ventilation system to evacuate smoke from the weld area, protecting the welding process and providing maximum visibility. FCAW-S may be used in the field under windy conditions that will remove the smoke from the weld area.

Flux cored arc welding (FCAW) is used for many of the same welding applications that use gas metal arc welding (GMAW) or shielded metal arc welding (SMAW). With FCAW, higher deposition rates are possible, there is no stub loss, and less time is wasted switching electrodes.

FCAW Equipment
Figure 22-2

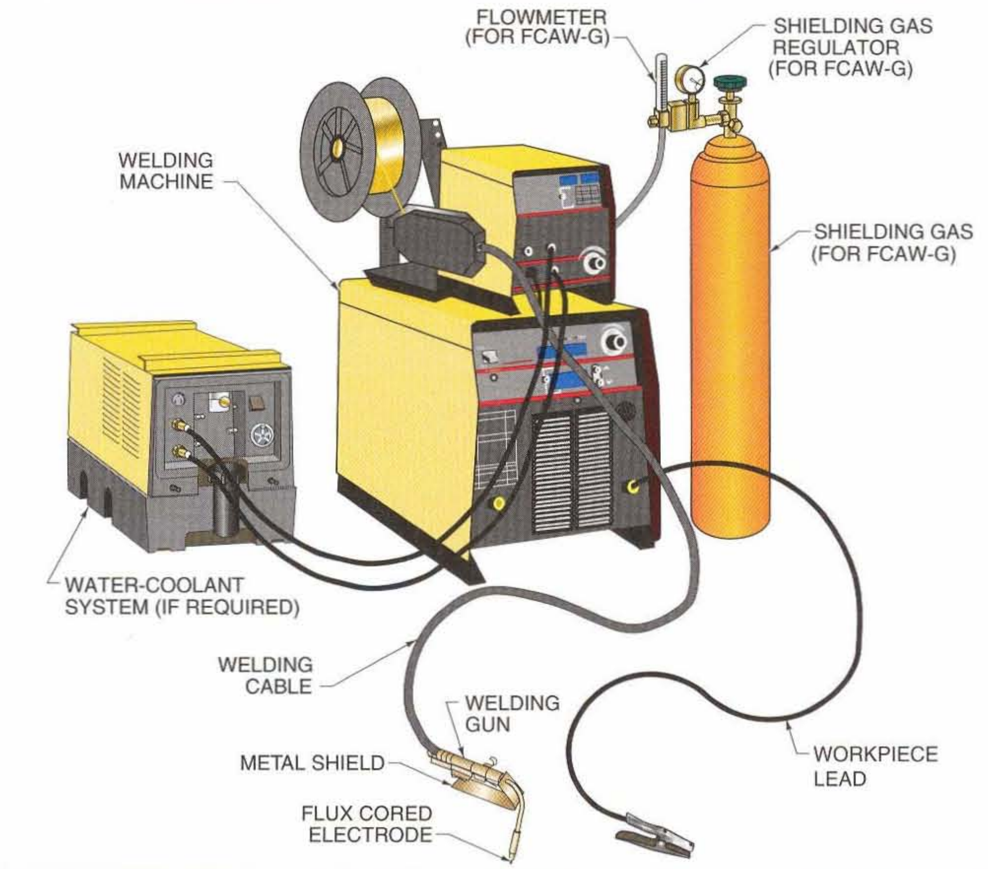


Figure 22-2. *FCAW equipment consists of a DC welding machine, a wire feeder, welding cables, and a welding gun. Additionally, a flowmeter, shielding gas regulator, and shielding gas are required for FCAW-G.*

Nederman, Inc.

Figure 22-3. *Fume extractors are commonly installed within a permanent ventilation system in a shop.*

Welding Machines

Welding machines used for FCAW must be capable of the higher currents and voltages required compared to GMAW. Typically, a DC current, constant-voltage welding machine is used for both FCAW-S and FCAW-G. See Figure 22-4.

A constant-voltage welding machine can maintain a constant arc length, delivering more current to the work to melt the electrode faster and more consistently than other welding machines. When using AC current, a constant-current welding machine is commonly used.

Weld requirements determine the type of welding machine selected for a particular application. The welding machine must be able to handle the largest size and type electrode required for the application. Large-diameter flux cored electrodes can require up to 650 A.

A DC current, constant-voltage welding machine is typically used for FCAW-S and FCAW-G.

Miller Electric Manufacturing Company

Figure 22-4. *The welding machine used for flux cored arc welding is typically a constant-voltage welding machine, similar to that used for GMAW.*

Welding Gun

The welding gun selected is determined by the type of FCAW process used, and the highest current required for welding.

The welding gun selected is determined by the FCAW process (FCAW-S or FCAW-G) being used, and the highest current required for welding. The welding gun must be capable of delivering the electrode, current, and shielding gas, to the weld area; and circulating cooling water (if required) through the system. The types of welding guns available include pistol grip, air-cooled, and water-cooled.

Pistol grip welding guns provide for straighter feeding of large-diameter electrode wire than other types of welding guns. Air-cooled welding guns are used with low current and low duty cycles. Water-cooled welding guns are used when welding with high current or high duty cycles. Generally, welding applications that require greater than 600 A require a water-cooled gun and a water-coolant system to prevent overheating.

A welding gun used for FCAW-S requires a metal shield to protect the welder from heat and spatter from the weld metal. FCAW-S welding guns do not have a shielding gas nozzle, allowing greater access to the weld joint. See Figure 22-5.

The flux in a flux cored electrode includes ionizers to stabilize the arc, deoxidizers to purge the deposits of gas and slag, and other metals to produce strong, ductile, and tough weld deposits.

Some FCAW welding guns have fume extractors to remove smoke and/or toxic fumes caused by the welding process. Fume extractors increase the visibility of the weld and reduce air pollution of the welding environment, but also add weight and bulk to the welding gun. Properly set fume extractors do not remove shielding gas from the weld area. Shielding gas, if used, is controlled by the same type of equipment used for GMAW.

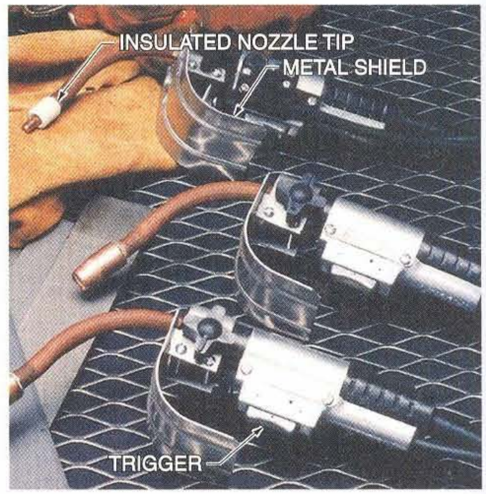


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Figure 22-5. *An FCAW-S welding gun has an insulated nozzle tip, a metal shield to protect the welder from slag and spatter, and a trigger to start and stop welding.*

Flux Cored Electrodes

Flux cored electrodes are often referred to as "inside-out" coated electrodes because the flux material is contained within the core of the electrode. Most flux cored electrodes used for FCAW are classified by the AWS as tubular wire electrodes. A letter-number combination (such as T-7) at the end of the AWS classification describes the specification of flux cored electrodes for FCAW. See Figure 22-6.

Tubular, mild steel, flux cored electrodes contain a core of flux materials that produce a gaseous shield, deoxidizing agents, and slag. Tubular electrodes are designed for high current densities and deposition rates which, when combined with high duty cycles, result in sharply increased production rates. The gaseous shield prevents contamination of the weld before solidification and protects the weld from slag.

COMMON CARBON STEEL FLUX CORED ELECTRODES			
AWS Classification	**Welding Current**	**Shielding**	**Single or Multiple Pass**
EXXT-1	DCEP	Ar-CO_2	Multiple
EXXT-2	DCEP	Ar-CO_2	Single
EXXT-3	DCEP	None	Single
EXXT-4	DCEP	None	Multiple
EXXT-5	DCEP OR DCEN	Ar-CO_2	Multiple
EXXT-6	DCEP	None	Multiple
EXXT-7	DCEN	None	Multiple
EXXT-8	DCEN	None	Multiple
EXXT-10	DCEN	None	Single
EXXT-11	DCEN	None	Multiple
EXXT-G	–*	–*	Multiple
EXXT-GS	–*	–*	Single

* agreed between purchaser and supplier

Figure 22-6. *Electrodes are classified by a letter and number combination, which reflects the ideal conditions under which the electrode should be used.*

Ionizers in the flux stabilize the arc. Deoxidizers purge the weld deposit of gas and slag. Other metals in the flux help to produce strong, ductile, and tough weld deposits. As the flux generates the gas shield, it also produces a slag covering that retards the cooling rate and protects the weld deposit from contaminants as it solidifies.

Care must be taken when welding multiple pass welds to prevent buildup of deoxidizing agents in the weld. Buildup of deoxidizing agents can result in lower ductility of the weld.

The electrode size and base metal thickness determine welding parameters such as current, wire feed speed, and shielding gas flow required. See Figure 22-7.

FCAW-S requires higher current levels than other welding processes. Proper electrode extension must be used throughout welding to maintain the required current. Proper electrode extension allows the electrode to be preheated as it passes through the contact tip, melting the flux material and producing the shielding gas. Proper electrode extension is based on the specifications for a particular application. If improper electrode extension is used, the flux will not be properly preheated and will not melt as it reaches the arc. Improper electrode extension can also lead to porosity in the weld.

A flux cored electrode can be used with or without CO_2 as a shielding gas, with DCEP or DCEN, and for single or multiple pass welding in either flat or horizontal position, depending on the type of electrode used. Although most FCAW is performed using DCEP, some electrodes may be designed specifically for use with DCEN.

Carbon dioxide is used as a shielding gas for FCAW, and many electrodes are manufactured specifically for use with CO_2. If an argon shielding gas mixture is specified, the electrode used must be compatible. If an electrode not specifically designed for use with a shielding gas mixture is used, deoxidizers could remain in weld deposit, producing an unacceptable weld.

When welding multiple pass welds, care must be taken to prevent buildup of deoxidizing agents in the weld. Buildup of deoxidizing agents can result in lower ductility of the weld.

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FCAW can be used to fabricate products in all positions.

FLUX CORED ARC WELDING CONDITIONS								
	Material Thickness*1	Current DCEP†	Arc Voltage	Wire Feed‡	Shielding Gas Flow§2	Travel Speed‡	No. of Passes	Electrode Extension
Flux cored arc welding of steel using 3/32″ diameter electrode (flat and horizontal positions)	1/8	300 – 350	24 – 26	100 – 120	35 – 40	25 – 30	1	3/4 to 1 1/2
	3/16	350 – 400	24 – 28	120 – 150	35 – 40	25 – 35	1	3/4 to 1 1/2
	1/4	350 – 400	24 – 28	120 – 150	35 – 40	20 – 30	1	3/4 to 1 1/2
	3/8	475 – 500	28 – 30	180 – 210	35 – 40	15 – 20	1	3/4 to 1 1/2
	1/2	400 – 450	25 – 28	150 – 170	35 – 40	18 – 20	2 – 3	3/4 to 1 1/2
	5/8	400 – 450	25 – 28	150 – 170	35 – 40	14 – 18	2 – 3	3/4 to 1 1/2
	3/4	400 – 450	25 – 28	150 – 170	35 – 40	14 – 18	5 – 6	3/4 to 1 1/2

Electrode Size*	Flat Position3		Horizontal Position3		Vertical Position3	
	(current)4	(voltage)5	(current)4	(voltage)5	(current)4	(voltage)5
.045	150 – 225	22 – 27	150 – 225	22 – 26	125 – 200	22 – 25
1/16	175 – 300	24 – 29	175 – 275	25 – 28	150 – 200	24 – 27
.068	175 – 325	24 – 26	175 – 325	24 – 26	—	—
5/64	200 – 400	25 – 30	200 – 375	26 – 30	175 – 225	25 – 29
.072	225 – 350	23 – 25	175 – 315	22 – 24	175 – 225	23 – 25
3/32	300 – 500	25 – 32	300 – 450	25 – 30	—	—
7/64	400 – 525	26 – 33	—	—	—	—
1/8	450 – 650	28 – 34	—	—	—	—

* in in.
† in amps
‡ in ipm
§ for FCAW-G, in cubic feet per hour (cfh)
1 for groove and fillet welds. Material thickness also indicates fillet size. Use V groove for 1/4″ and thicker double-V for 1/2″ and thicker
2 welding grade CO_2
3 applies to groove, bead, or fillet welds in position shown
4 current range can be expanded. Higher currents can be used, especially with automatic travel
5 voltage range can be expanded. It will increase when higher electrode–to–work distance is used

Figure 22-7. *Flux cored arc welding conditions must be properly maintained, and are determined by the electrode size and the material thickness.*

Wire Feeder

The wire feeder used with FCAW is determined by the wire feed speed and the size of the electrode. The wire feeder provides a constant, preset feed speed into the welding arc. As with GMAW, the wire feed speed determines the welding current that a constant-voltage welding machine supplies. Increasing or decreasing the wire feed speed on the wire feeder changes the welding current.

⚠ CAUTION

Electrodes selected for FCAW must be compatible with the shielding gas used.

For some applications, a constant-current welding machine may be used with a voltage-sensing wire feeder that varies the wire feed speed depending upon the arc length between the unmelted electrode and the base metal.

A push type wire feeder is most commonly used because of the rigidity of the flux cored electrode. The wire feeder drive rolls used for flux cored electrodes greater than 1/16″ in diameter are knurled to prevent slippage when resistance from long or bent welding cables occurs.

Flux cored electrodes are typically designed to be used with CO_2 and are intended for high current densities.

Wire feeders may be equipped with two or four drive rolls. Constant-speed wire feeders typically have two drive rolls that grasp the electrode and push it through the welding gun. When a large-diameter electrode is required, a four-drive-roll wire feeder is commonly used. A four-drive-roll wire feeder provides smooth feeding of the electrode by providing a straightening effect.

Shielding Gas

Carbon dioxide is commonly used as a shielding gas because it yields deep penetration, has good impact properties, and produces less smoke and fumes than other gases. CO_2 is also one of the least expensive shielding gases available, making it a cost-effective gas for FCAW-G. Required gas flow rates vary depending on the electrode type, electrode extension, joint design, air movement around the weld, etc. Gas flow rates can range from 35 cfh to 45 cfh.

Shielding gas cylinders, a regulator and gas flowmeter, and welding cables to deliver the shielding gas (and coolant if required) are used to deliver the shielding gas to the weld

area. A water-coolant system may be used when welding at current levels above 500 A to prevent high temperatures from developing during welding.

The flowmeter should be regularly inspected to prevent icing up at high flow rates. High volume regulators or heater-equipped regulators help prevent icing up as well. Icing up of the regulator can allow moisture to enter the weld area and cause porosity.

Gas mixtures such as an argon-carbon dioxide (Ar-CO_2) mixture may be used for FCAW. A common mixture is 75% Ar and 25% CO_2. An Ar-CO_2 mixture may be used for out-of-position welding and when high tensile and yield strengths are required. An Ar-CO_2 mixture provides better arc characteristics for out-of-position welding.

When welding on stainless steel using FCAW, a 98% Ar/2% O_2 shielding gas mixture may be used. The externally supplied shielding gas mixture works with gas produced by the flux cored electrode to shield the arc.

Argon and other gases are odorless. Odorless gases may go undetected and displace oxygen in enclosed spaces. Always check for leaks prior to use and use proper ventilation when using shielding gases.

FCAW APPLICATIONS

FCAW combines the production efficiency of GMAW and the penetration and deposition rates of SMAW. In addition, FCAW is useful when shielding gas is unavailable. The most common application of FCAW is structural fabrication. High deposition rates achieved in a single pass make FCAW popular in the railroad, shipbuilding, and automotive industries. FCAW can be used in all positions with the proper electrode and required shielding gas. FCAW can be used to weld carbon steels, low-alloy steels, various stainless steels, and some cast irons.

When straight CO_2 is not used as a shielding gas for FCAW, a common gas mixture is 75% Ar/25% CO_2.

POINTS TO REMEMBER

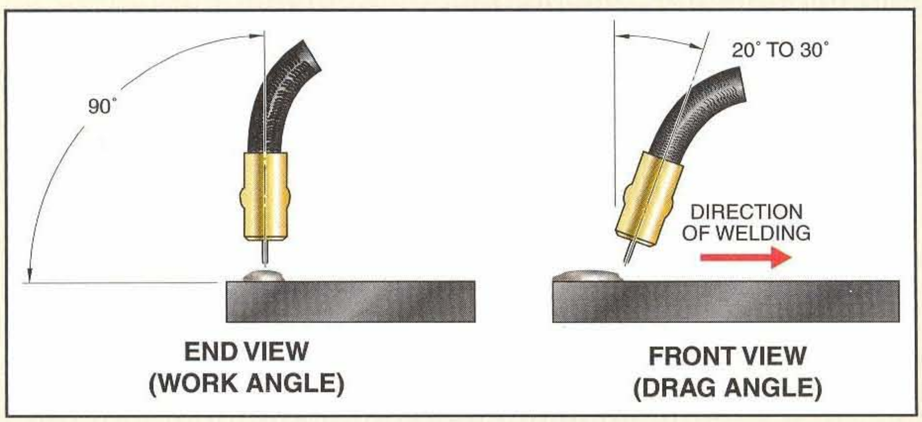
1. Self-shielded flux cored arc welding (FCAW-S) is an FCAW variation in which shielding gas is provided exclusively by the flux within the electrode.
2. Gas-shielded flux cored arc welding (FCAW-G) is an FCAW variation in which the shielding is obtained from both the CO_2 gas flowing from the gas nozzle and from material contained within the flux core of the electrode.
3. FCAW produces a quality weld at lower cost with less effort than SMAW, and is more flexible than SAW.
4. A DC current, constant-voltage welding machine is typically used for FCAW-S and FCAW-G.
5. The welding gun selected is determined by the type of FCAW process used, and the highest current required for welding.
6. The flux in a flux cored electrode includes ionizers to stabilize the arc, deoxidizers to purge the deposits of gas and slag, and other metals to produce high strength, ductility, and toughness in weld deposits.
7. Care must be taken to prevent buildup of deoxidizing agents in the weld. Buildup of deoxidizing agents can result in lower ductility of the weld.
8. Flux cored electrodes are typically designed to be used with CO_2 and are intended for high current densities.
9. When straight CO_2 is not used as a shielding gas for FCAW, a common gas mixture is 75% Ar/25% CO_2.

Exercises

Depositing Beads on Mild Steel in Flat Position

exercise 1

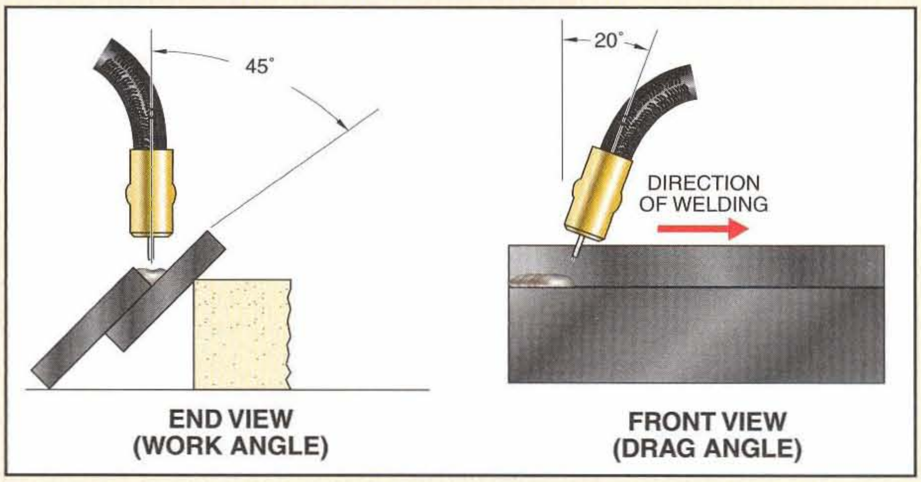
1. Obtain a 3⁄32″, E70T-1 flux cored electrode.
2. Feed the electrode through the wire feeder to the welding gun and set the electrode extension between 1″ and 1½″.
3. Set the welding machine output for DCEP.
4. Set the shielding gas (carbon dioxide) at 40 cfh.
5. Set the wire feed control so that the ammeter reads between 390 A and 410 A. To obtain the correct reading, have another person observe the current while welding is being performed.
6. Set the voltage to 26 V to 28 V using the same procedure as in step 5.
7. Obtain a piece of mild steel ½″ to 1″ thick, 4″ wide, and 6″ long.
8. Position the workpiece in flat position.
9. Position the welding gun at a 90° work angle and a 20° to 30° drag angle.
10. Maintain a bead that is approximately ¾″ wide and ⅛″ to ¼″ high.
11. Deposit a series of straight, consistent beads approximately ⅜″ apart.



Welding a Multiple-Pass Lap Joint on Mild Steel in Flat Position

exercise 2

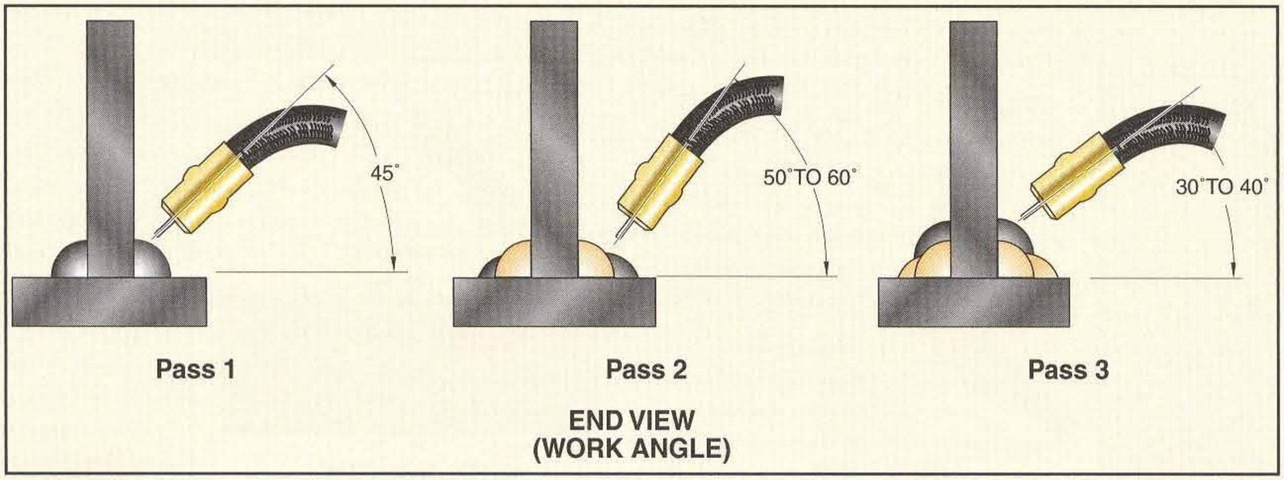
1. Complete equipment setup and adjustment as in Exercise 1.
2. Obtain two pieces of mild steel ¾″ to 1″ thick, 2″ wide, and 6″ long.
3. Form a lap joint and tack together.
4. Position the workpiece so the weld joint is in flat position.
5. Position the welding gun at a 45° work angle and a 20° drag angle. Deposit the first pass on both sides of the lap joint.
6. Use a weaving motion and deposit the second pass on both sides of the lap joint. Pause at the toes of the weld to prevent undercutting.
7. Deposit the third pass on both sides of the joint using the same procedure as for the second pass.



Welding a Multiple-Pass T-Joint in Horizontal Position

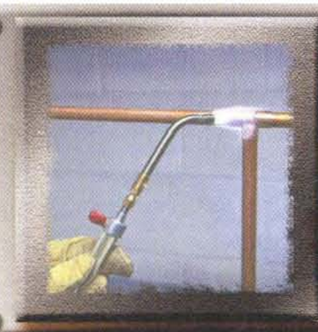
exercise 3

1. Complete equipment setup and adjustment as in Exercise 1.
2. Obtain two pieces of mild steel ¾″ to 1″ thick, 2″ wide, and 6″ long.
3. Form a T-joint with the workpieces at a 90° angle and tack together.
4. Position the workpiece so the weld joint is in horizontal position.
5. Position the welding gun at a 45° work angle and a 20° drag angle and deposit the first pass on both sides of the T-joint.
6. Position the welding gun one electrode diameter below the bottom toe of the root bead and deposit the second pass on both sides of the T-joint using a 50° to 60° work angle and a 20° drag angle.
7. Deposit the third pass on both sides of the T-joint using a 30° to 40° work angle and a 20° drag angle.



QUESTIONS FOR STUDY AND DISCUSSION

1. What is the basic difference between FCAW and GMAW?
2. What type of welding machine is most commonly used for FCAW?
3. How does flux protect the weld metal from contaminants?
4. Why is the push-type wire feeder used for FCAW?
5. What equipment is required for the FCAW-S process?
6. Why must buildup be prevented when using flux cored electrodes?
7. What equipment is required for the FCAW-G process?
8. Why is CO_2 preferred as a shielding gas for FCAW-G?
9. How are electrodes selected for FCAW-G?



23 Brazing, Braze Welding, & Soldering

Other Welding Processes

Brazing and soldering differ from welding in that joining occurs when filler metal is added at temperatures below the melting point of the metals joined. Soldering also uses nonferrous filler metals with melting temperatures below 840°F (450°C).

Braze welding is slightly different from conventional brazing. In braze welding, filler metal is deposited in standard weld joints. Capillary action is not a factor in distribution of the filler metal. Braze welding is adaptable for joining or repairing metals such as cast iron, malleable iron, copper, and brass. Braze welding can also be used to join dissimilar metals such as cast iron and steel.

BRAZING

Brazing (B) is a group of joining processes that produce a coalescence of metals using nonferrous filler metals that have a melting point below that of the base metal. Filler metals suitable for brazing are those that begin to melt, or change to a liquid state, above 840°F (450°C). During brazing, the joined metals remain in a solid state. Filler metal is distributed between the closely fitted surfaces of the joint by capillary action. *Capillary action* is the force that distributes liquid filler metal through surface tension between the faying surfaces of the joint. The *faying surface* is the point of contact between two members to be joined.

Most metals can be brazed, including copper and copper alloys, stainless steels, magnesium alloys, aluminum alloys, carbon and low-alloy steels, cast irons, titanium and titanium alloys, and zirconium and zirconium alloys. Brazing is also used for joining dissimilar metals. One exception is that copper and copper alloys cannot be brazed directly to aluminum or aluminum alloys.

Most brazed joints have a relatively high tensile strength, but they do not possess the full strength properties produced by other welding techniques.

A characteristic of brazing is that the properties of the HAZ are not impaired during brazing because lower bonding temperatures are used than in welding. For sound brazed joints the following requirements must be met:

- Use proper joint design to allow capillary action of the filler metal and adequate surface area.
- Use proper surface preparation to ensure wetting of surfaces by the filler metal.
- Use correct fluxes for a controlled atmosphere and to prevent surface oxidation.
- Use correct filler metal, which should meet AWS standards when possible.
- Use proper heating equipment to provide specified brazing temperature and heat distribution.

Additionally, for brazing, the following criteria are necessary:

- Parts are joined without melting of the base metal.
- Filler metal begins to melt above 840°F (450°C).
- Filler metal wets the base metal and is drawn into, or held in, the joint by capillary action.

Brazing filler metal must be molten before it flows into a joint. The melting temperature of filler metals varies depending on the type of filler metal. Filler metal must have a liquidus temperature lower than the solidus temperature of the base metal. *Liquidus temperature* is the temperature at which a metal is completely molten. *Solidus temperature* is the highest temperature that a metal can reach and remain in a solid state. The lowest effective brazing temperatures possible should be used to minimize the effects of heat on the base metal. Excess heat on the base metal can cause grain growth, warpage, and hardness reduction.

Use the lowest effective brazing temperatures to minimize grain growth, warpage, and hardness reduction.

Joint Design

Joint design is based on adhesive qualities of the filler metal. Two joints used for brazing are the lap joint and butt joint. A lap joint is commonly used because it offers a large surface area for the greatest strength. For maximum efficiency, the overlap should equal or exceed three times the thickness of the thinnest member. The main drawback of a lap joint is that metal thickness at the joint is increased. For joint design purposes, T-joints and corner joints are treated as butt joints.

Joint design for brazing is based on the adhesive qualities of the filler metal and on joint clearance.

A butt joint does not provide the same strength as a lap joint because its cross-sectional area is equal only to the cross-sectional area of the thinnest member. Higher strengths can be achieved by scarfing the edges; however, greater care is required to prepare the joint and keep the pieces aligned. The strength of a butt joint can be improved using a sleeve. See Figure 23-1.

Joint design is also based on joint clearance. Joint clearance has a major effect on the mechanical properties of a brazed joint. Surfaces that fit too tightly together hinder the flow of molten filler metal.

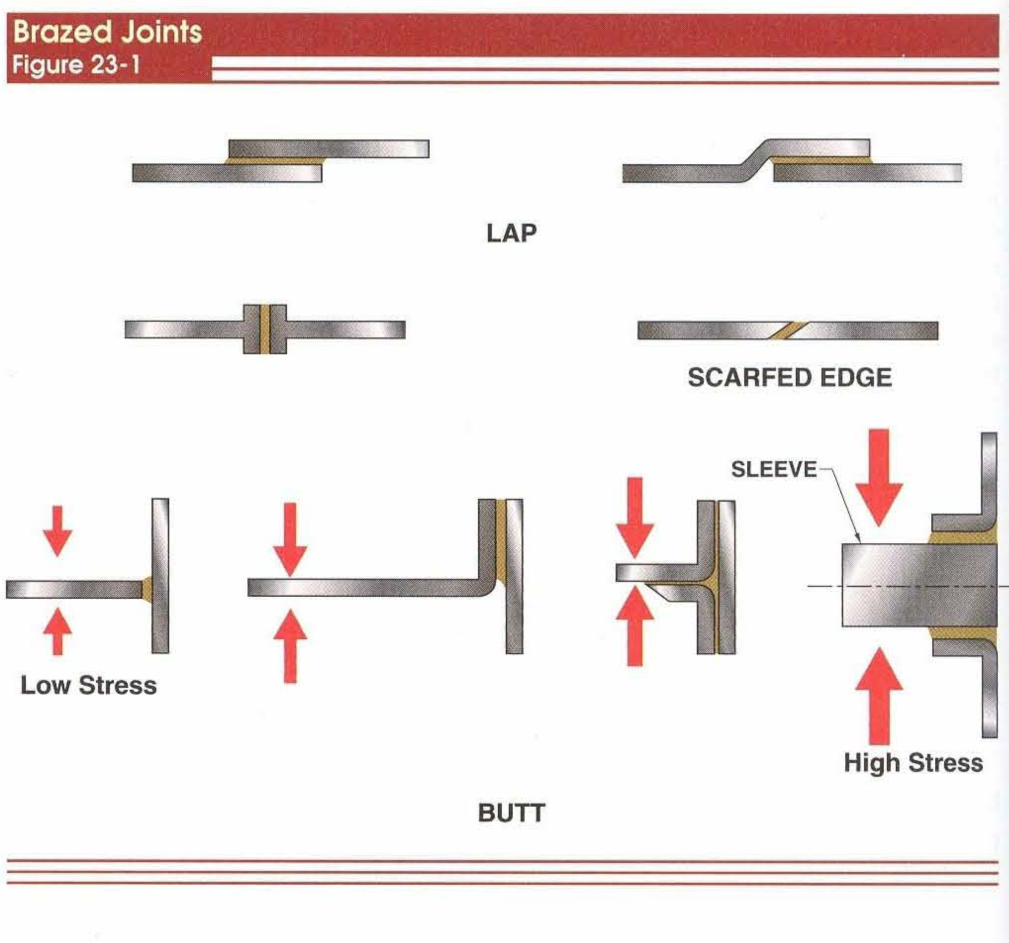


Figure 23-1. *Lap joints and butt joints are used for brazing. Edges of the joint may be scarfed to attain higher joint strength.*

Surfaces that fit too loosely at the joint prevent the full effects of capillary action, leaving voids and poor distribution of filler metal. Adequate joint clearance is in the range between .001″ and .010″. Recommended joint clearances vary with the type of filler metal used. See Figure 23-2.

When welding dissimilar metals, particular attention must be paid to joint design, as all metals have different expansion rates. Varying expansion rates must be considered if parts are to be clamped, fitted together, or restrained in a jig.

Surface Preparation

Clean, oxide-free surfaces are necessary to make sound brazed joints. Uniform capillary action is only possible when surfaces are completely free of foreign substances such as dirt, oil, grease, and oxide. Foreign substances can be removed by immersing a part in a commercial-cleaning solvent or salt bath; by pickling in acid (sulfuric, nitric, or hydrochloric); or by using a vapor-degreasing unit. Surface oxide can be eliminated by sanding, grinding, filing, machining, blast cleaning, or wire brushing. The method used depends on the contaminants, the joint design, and type of metal to be brazed.

When cleaning the surface, prevent wearing the faying surfaces too smooth. If the faying surfaces are too smooth, filler metal will not be able to effectively wet the joint. Smooth surfaces can be roughened by rubbing with a 30-grit (coarse) or 40-grit emery cloth. Brazing should be performed as soon as the metal is cleaned to prevent contamination from atmospheric exposure or handling.

Flux and Stopoffs

Metal surfaces are easily contaminated from the atmosphere after they are cleaned. Some metals are more susceptible to contamination than others. Any chemical reaction resulting from air exposure is accelerated as the temperature is raised during the brazing process; therefore, a flux is needed to dissolve and remove oxides that may form during brazing. Flux may contain boric acid, borates, fluorides, fluoroborates, chlorides, and/or wetting agents. The purpose of a flux is to prevent or inhibit the formation of

Surfaces to be brazed must be completely free of oil, grease, dirt, and oxide.

BRAZING JOINT CLEARANCE

Filler Metal Group	Joint Clearance*	Brazing Joint Clearance†
BA1Si	.002 – .008	For lap length less than ¼″
	.008 – .010	For lap length greater than ¼″
BCuP	.001 – .005	No flux and flux brazing
BAg	.002 – .005	Flux brazing
	.001 – .002‡	Gas phase (atmosphere) brazing
BAu	.002 – .005	Flux brazing
	.000 – .002‡	Gas phase (atmosphere) brazing
BCu	.000 – .002‡	Gas phase (atmosphere) brazing
BCuZn	.002 – .005	Flux brazing
BMg	.004 – .010	Flux brazing
BNi	.002 – .005	Flux or gas phase (atmosphere) brazing
	.000 – .002	Free flowing or gas phase (atmosphere) brazing

* in in.
† joint clearance on the radius when rings, plugs, or tubular members are used. Use recommended clearance on the diameter to prevent excessive clearance when all the clearance is on one side. Excessive clearance produces voids especially in gas phase brazing
‡ for maximum strength, use a press fit of .001 in./in. of diameter

Figure 23-2. *An accurate joint clearance is necessary for optimum strength of brazed joints.*

Always use an appropriate filler metal and flux that is recommended for the metal to be brazed.

oxide during the brazing process. Flux is not intended to remove contamination that is already present on metal, such as dirt, grease, and oil. See Figure 23-3. A *stopoff* is a material used to outline areas that are not to be brazed. Stopoffs consist of various compounds made into slurries that effectively prevent the ingress of filler metal.

The flux used for brazing must readily promote the fluidity of the filler metal. Equally important is its surface tension, since this affects the wettability of the base metal and its flow in the joint. Finally, a flux must last long enough to counteract any reactive effects developed during brazing. Some brazing filler metals are precoated with a flux.

Flux is available in powder, paste, or liquid form. Fluxes must be selected to suit a particular metal. Paste flux and powder flux are commonly used for brazing. Paste flux can be applied to a joint before brazing and provides good adherence. Powder flux is sprinkled on the joint or applied to the heated end of the filler metal by dipping the filler metal into the flux container. See Figure 23-4. A liquid flux is used mostly for torch brazing. The fuel gas is passed through the liquid flux, which carries the flux along and deposits it wherever the flame is applied.

Controlled Atmosphere. A controlled atmosphere may also be used to prevent the formation of oxides during brazing. In a controlled atmosphere, a gas is continuously supplied to a furnace and circulated at slightly higher than atmospheric pressures. The gas used may consist of high-purity hydrogen, carbon dioxide, carbon monoxide, nitrogen, argon, ammonia, or some form of combusted fuel gas.

BRAZING FLUX					
AWS Brazing Flux*	**Base Metals**	**Filler Metals†**	**Useful Range‡**	**Flux Agent**	**Available as:**
1	All brazeable aluminum alloys	BAlSi	700 – 1190	Chlorides Fluorides	Powder
2	All brazeable magnesium alloys	BMg	900 – 1200	Chlorides Fluorides	Powder
3A	All except those listed under 1, 2, and 4	BCuP, BAg	1050 – 1600	Boric Acid Borates Fluorides Fluoroborates	Powder Paste Liquid
3B	All except those listed under 1, 2, and 4	BCu, BCuP, BAg, BAu, RBCuZn, BNi	1350 – 2100	Wetting Agent Boric Acid Borates Fluorides Fluoroborates	Powder Paste Liquid
4	Aluminum bronze, aluminum brass and iron or nickel base alloys containing minor amounts of Al and/or Ti	BAg (all) BCuP (Copper based alloys only)	1050 – 1600	Wetting Agent Chlorides Fluorides Borates Wetting Agent	Powder Paste
5	All except those listed under 1, 2, and 4	Same as 3B (excluding BAg-1 through-7)	1400 – 2200	Borax Boric Acid Borates Wetting Agent	Powder Paste Liquid

* flux type No.
† recommended
‡ °F

Figure 23-3. *Flux prevents the formation of oxide or other undesirable substances during brazing, but does not remove contamination that is already present on the metal.*

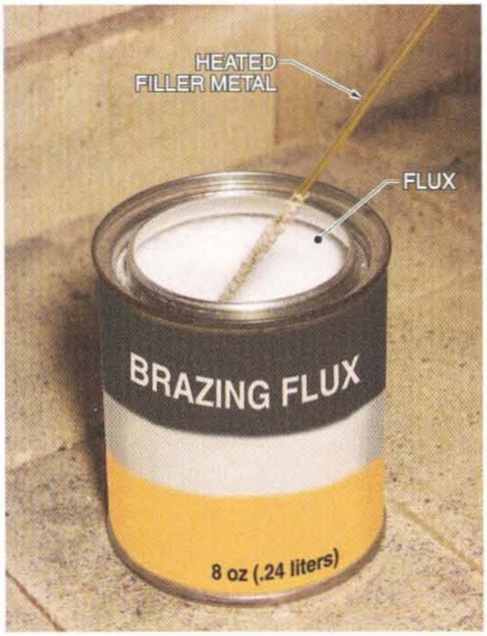


Figure 23-4. *To apply a powder flux, heat the filler metal and dip it into the flux, making sure the filler metal is thoroughly coated.*

Filler Metals (Brazes)

Some filler metals for brazing are manufactured with a flux coating. Brazing filler metals are available in wire, rod, strip, and powder forms. Filler metals are designed to braze different metals. The AWS specifies that brazing filler metals have the following characteristics:

- be able to wet the base metal and form a strong bond between the base metal and filler metal
- have a melting temperature that permits adequate distribution by capillary action
- have sufficient homogeneity and stability to minimize separation by liquation (separation of the solid and liquid portion) and not be excessively volatile
- be capable of producing a brazed joint to meet service requirements such as strength and corrosion resistance

Filler metals may be designated by commercial names or AWS classification symbols. The AWS classification consists of the letter B, which identifies it as brazing filler metal, followed by the chemical symbols of the metallic elements included in the filler metal. See Figure 23-5. Digits following a dash are shown after the chemical symbols to designate specific filler metals within the group.

Filler Metal Application. Brazing filler metal and flux can be applied manually after the work is heated, or pre-placed in a suitable position before the work is heated. Rod and wire are generally used for manual face-feeding. Pre-placed filler metals are usually in the form of rings, washers, formed wire, shims, and powder, and are located near the joint to ensure a uniform flow of filler metal into the joining surfaces. Although pre-placed filler metals can be used in manual brazing, they are more commonly used for production work in furnace, induction, or dip brazing.

BRAZING FILLER METALS

AWS Classification of Brazing Filler Metals	Types of Metals to be Brazed
BAlSi (aluminum-silicon)	Aluminum, aluminum alloys
BCuP (copper-phosphorus)	Copper, copper alloys
BAg (silver)	Ferrous and nonferrous metals except aluminum and magnesium
BAu (precious metals)	Iron, nickel, and cobalt base metals
BCu (copper)	Ferrous and nonferrous metals
BCuZn (copper-zinc)	Ferrous and nonferrous metals
BNi (nickel)	Stainless steels, carbon steels, low-alloy steels, copper
BMg (magnesium)	Magnesium, magnesium alloys

Figure 23-5. *The AWS classifies filler metals by the symbol of the metallic elements that are included in the filler metal.*

When using oxyacetylene or MAPP-oxygen gas mixtures, heat the surfaces with the outer envelope of the flame and not the inner cone.

Manual Brazing

The heat required for manual brazing methods is typically applied using a gas torch. The gas mixture can be oxyacetylene, air-gas, gas-oxygen, oxyhydrogen, or MAPP-oxygen. The gas mixture used depends on the thermal conductivity, type, and thickness of the metal to be brazed. See Figure 23-6.

Smith Equipment

Figure 23-6. *A gas torch is commonly used for manual brazing.*

Oxyacetylene or MAPP-oxygen is generally more versatile because its heat can be controlled over a wide temperature range. With either of these gas mixtures, a slightly reducing flame is required. Only the outer envelope of the flame and not the inner cone should be applied to the work.

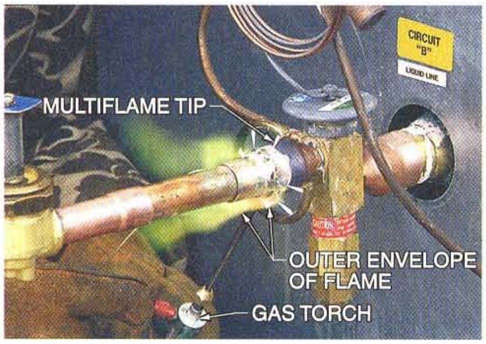
The air-gas torch provides the lowest heat and has greater application in brazing light-gauge metals. Air-gas mixtures may use air at atmospheric pressure and city gas or an air-acetylene mixture.

A gas-oxygen mixture uses oxygen and city gas, bottled gas, propane, or butane. The gas-oxygen mixture produces a high flame temperature and is effective where higher brazing heat is required.

An oxyhydrogen mixture, due to the low heat it produces, is used for brazing aluminum and other nonferrous metals. The low temperature prevents overheating and the hydrogen provides a cleaning action and shielding during the brazing process. For brazing applications on most metals, follow the procedure:

1. Determine the most suitable joint for the work to be brazed.
2. Review safety practices per ANSI Z49.1, *Safety in Welding and Cutting*. This includes assessing the need for personal protective equipment, assessing ventilation requirements, reviewing relevant MSDSs, and assessing potential hazards such as fires.
3. Remove dirt, grease, oil, and oxides from surfaces to be brazed.
4. Select the correct flux and apply it to both the workpieces and the filler metal by brushing, dipping, sprinkling, or spraying.
5. Assemble the workpieces and keep them in alignment using clamps, fixtures, or jigs. Do not apply excessive pressure because enough clearance between the faying surfaces must exist to allow a free flow of filler metal.
6. Preheat the entire work area to a uniform brazing temperature by playing a torch over the workpiece surface.
7. Once the flux is completely fluid, touch the filler metal to the joint. Keep applying filler metal until it flows completely through the joint. Use a slightly reducing flame and do not apply the inner cone of the flame directly to the filler metal or the workpiece.
8. Clean the brazed joint to remove flux residue or debris.
9. Visually inspect the brazed joint. The joint should be free from grease, paint, oil, oxide film, and stopoff. The part should retain dimensional conformance and there should be no visible interruption to the flow of filler metal. There should be no cracks or porosity. Visual inspection cannot detect internal discontinuities. The procedure specification will indicate specific nondestructive procedures that must be performed.

Brazing using silver filler metals can be used for high stress applications that may be subjected to system vibration, and expansion and contraction that occurs on heating and cooling. See Figure 23-7.



Smith Equipment

Figure 23-7. *When brazing, only the outer envelope of the flame should be applied to the work.*

Production Brazing

Although torch brazing can be mechanized for production purposes, higher production rates are usually accomplished using furnace heating, induction brazing, resistance brazing, or dip-brazing techniques. Production brazing methods ensure accurate heat control and high-quality brazed joints.

With furnace heating, parts to be brazed are positioned on trays, which are then placed in a gas, electric, or oil-fired furnace. Flux is generally used on the parts, unless the furnace atmosphere performs the function of a flux, or if cleaning of the brazed surfaces is not possible due to design complexities. The correct atmosphere must be used in a furnace and is determined by the type of base metal and filler metal used. See Figure 23-8.

Remove all flux residue after brazing is completed.

With induction brazing, the workpiece is placed near an induction coil. As current flows through the coil, the resistance of the coil to the flow of current causes instant heating to occur. The parts are placed in an AC current field, but do not become part of the circuit. Induction brazing is commonly used for high-volume manufacturing applications. Induction brazing provides rapid heating; however, it is difficult to obtain a uniform heating rate. See Figure 23-9.

Resistance brazing is similar to spot welding where heat is generated by the passage of low-voltage current

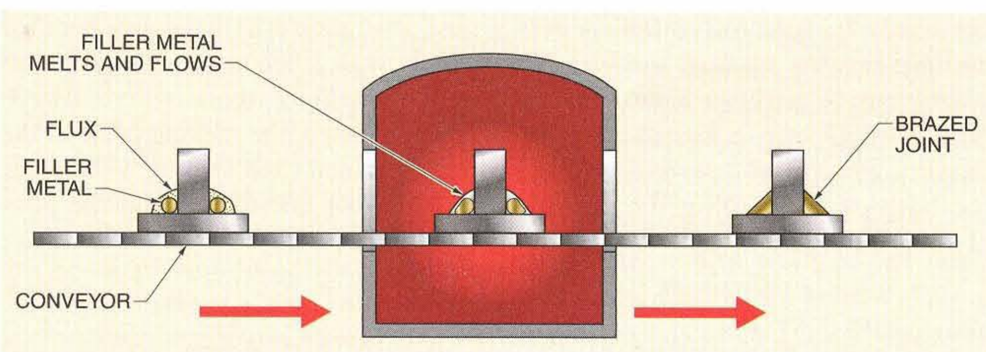


Figure 23-8. *Pre-placed filler metals are generally used for production brazing in a furnace.*

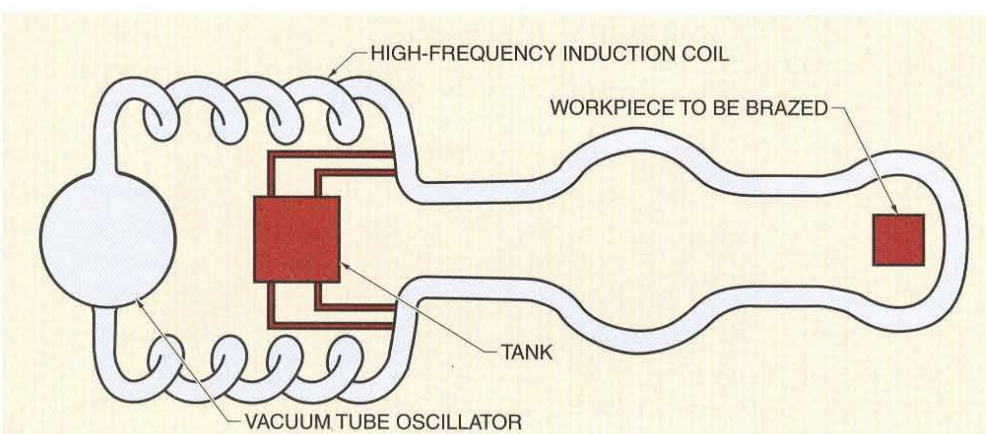


Figure 23-9. *In induction brazing, current flows through an induction coil. Resistance of the coil to the flow of current creates the necessary heat.*

through carbon electrodes that are clamped around the work. In resistance brazing, current flows through the parts being brazed and the parts become part of the electrical circuit. Resistance brazing is used with pre-placed flux and for low-volume production applications. See Figure 23-10.

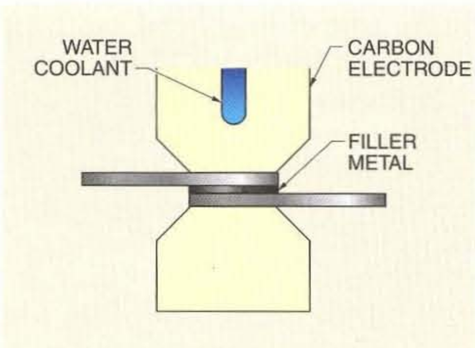


Figure 23-10. *In resistance brazing, current passes through carbon electrodes clamped around the work.*

One dip-brazing method consists of immersing parts in a bath of molten brazing metal. The brazing metal is contained in an externally heated crucible. See Figure 23-11. Dip-brazing is limited to small assemblies such as wire connections or metal strips that can easily be held in fixtures. A second dip-brazing method involves the placement of parts in a molten salt bath. The salt bath is heated either by passing electrical current through the bath or by heating the outside of the container.

Flux Removal

Once brazing is completed, flux residue must be removed to prevent corrosion from developing in the brazed joint. Flux residue has a glass-like surface appearance. Flux residue can be removed by washing the part in hot water. In some instances, the joint can be immersed in cold water before it has completely cooled from the brazing temperature. The thermal shock of the cold water will usually crack off the flux residue. For heavy residue, a chemical dip is sometimes used. Wire or fiber brushing, steam jet cleaning, or blast cleaning are also effective means of removing heavy residues or of removing flux residue from large objects. On some soft metals such as aluminum, residue must be removed mechanically and then cleaned with fluid to ensure removal of small flux particles that may have become embedded in the surface.

BRAZE WELDING

Braze welding (BW) is a joining process that produces a coalescence of metals with filler metals that begin to melt at temperatures above 840°F (450°C), below the melting point of the metals joined, and in which the filler metal is not distributed into the joint by capillary action.

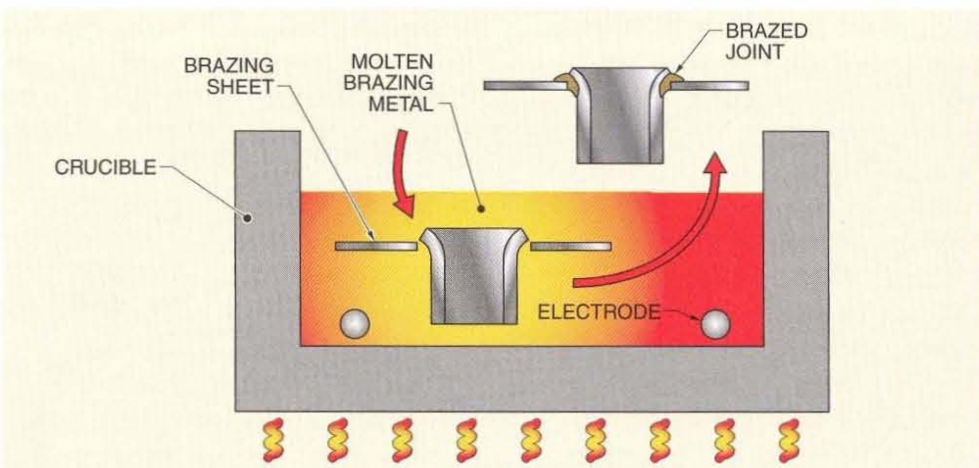


Figure 23-11. *In dip-brazing, parts are immersed in molten brazing metal inside an externally heated crucible.*

The braze welding procedure usually must be qualified. Eight basic steps are required to perform braze welding. For braze welding, follow the procedure:

1. Clean the surfaces to be brazed thoroughly with a stiff wire brush. Remove all scale, dirt, or grease; otherwise the braze will not stick. If a surface has oil or grease on it, remove these substances by heating the area to a bright red to burn them off.
2. On thick sections, especially when repairing castings, bevel the edges to form a 90° single-V. Edges can be beveled by chipping, machining, filing, or grinding.
3. Arrange the work in flat position.
4. Adjust the torch to a neutral flame then gently heat the surfaces of the weld area. The surfaces should not be melted, but only heated to a dull red (tinning temperature).
5. Heat the brazing filler metal and dip it in the flux. (This step is not necessary if the filler metal has been prefluxed.) When heating filler metal, do not apply the inner cone of the flame directly to the rod.
6. At the start, concentrate the flame on the base metal until the base metal begins to turn red. Melt a small amount of brazing filler metal onto the surface and allow it to spread along the entire seam. The flow of this thin film of filler metal is known as tinning. Unless the surfaces are tinned properly, braze welding cannot be carried out successfully.

   If the base metal is too hot, filler metal bubbles or runs like drops of water on a warm stove. If the base metal is not hot enough, filler metal forms into balls that roll off the base metal as water would if placed on a greasy surface. When the base metal is the proper temperature, the filler metal spreads out evenly.
7. Once the base metal is tinned sufficiently, deposit the proper size beads over the joint. Use a slight circular motion with the torch and deposit the beads as in regular fusion welding with a filler metal. Continually dip the filler metal in the flux as the weld progresses forward. See Figure 23-12.

Use a qualified procedure for braze welding.

Smith Equipment

Figure 23-12. *Use a slight circular motion with the torch when braze welding and deposit the beads using filler metal.*

Clean surfaces thoroughly before applying filler metal.

8. If the pieces to be welded are grooved, use several passes to fill the groove. On the first pass, ensure that the tinning action takes place along the entire bottom surface of the groove and about halfway up on each side. The number of tinning passes to be made depends on the depth of the groove. When depositing several passes, be sure that each pass is fused into the previous one.

When making a braze weld with the work in vertical position, first build up a slight shelf at the bottom. The shelf acts as a support for additional filler metal. As the weld is carried upward, swing the flame from side to side to maintain uniform tinning and to produce an even bead.

Be sure the surfaces are properly tinned before depositing beads.

Cast Iron Braze Welding

Braze welding is primarily used to repair broken cast iron parts. High preheat temperatures are not usually required unless the part is very heavy or complex in geometry. A maximum preheat of 200°F (93°C) is typically

⚠ CAUTION

When brazing or braze welding, make sure that the base metal is not allowed to overheat.

Use a neutral flame unless otherwise specified. Use a circular torch motion.

Do not braze weld a metal that will be subjected to high temperatures or high stresses.

sufficient. The heat of the flame or the arc is sufficient to bring the surface of the cast iron to a temperature at which the filler metal will bond to the cast iron. The filler metal ductility compensates for the brittleness of the cast iron, and the weld and adjacent area of the base metal are machinable after the weld is completed. Braze welding broken cast iron is acceptable if a color difference between the filler metal and the cast iron is not objectionable.

Filler Metal and Flux

Braze welding filler metals are usually brasses, with an approximate composition of 60% copper and 40% zinc, and which produce adequate tensile strength and ductility. In addition, filler metal contains small quantities of tin, iron, manganese, aluminum, lead, nickel, chromium, and silicon. These elements help deoxidize the weld metal, decrease the tendency to fume, and increase the free-flowing action of molten metal. See Figure 23-13.

A clean metal surface is essential for braze welding. For the filler metal to provide a strong bond, it should flow smoothly and evenly over the entire weld area. Adhesion of the molten filler metal to the base metal takes place only if the surface is chemically clean. Even after a metal surface has been thoroughly cleaned by mechanical means, certain oxides may still be present. These oxides can only be compensated for by using the correct flux.

Prefluxed brazing filler metal eliminates the need to apply flux while brazing. The flux may also be applied by dipping the heated filler metal into the powdered flux. The flux adheres to the surface of the filler metal and can then be transferred to the weld. Another method of applying flux is to dissolve the flux in boiling water and brush it on the filler metal before welding is started.

Braze Welding Disadvantages

One precaution that must be considered in braze welding is not to weld a metal that will be subjected to high temperatures in service. Filler metal loses its strength when exposed to high temperatures. Also, braze welding should not be used on steel parts that must withstand unusually high stresses.

SOLDERING

Soldering (S) is a group of joining processes that produce a coalescence of metal and nonferrous filler metal that has a melting point below that of the base metal. Filler metals suitable for soldering are those that are completely molten below 840°F (450°C). In soldering, the joined metals remain in a solid state and filler metal is distributed between the closely fitted surfaces of the joint by capillary action.

In both brazing and soldering, wetting and capillary action occur; however, in soldering, a small amount of alloying occurs between the base metal and the filler metal (solder). A major benefit of soldering is that low temperatures are involved, with a minimum effect on base metal properties. Many low-temperature heating

COPPER-ZINC FILLER METAL FOR BRAZE WELDING

AWS Classification*	Approximate Chemical Composition†					Min Tensile Strength		Liquidus Temperature	
	Copper	Zinc	Tin	Iron	Nickel	ksi	MPa	°F	°C
RBCu Zn-A	60	39	1			40	275	1650	900
RBCu Zn-C	60	38	1	1		50	344	1630	890
RBCu Zn-D	50	40			10	60	413	1714	935

* see AWS A5.7 and A5.8
† in %

Figure 23-13. *A copper-zinc filler metal is commonly used for braze welding.*

methods can be used in soldering with high reliability. Soldering is the primary method of making joints in electrical and electronic circuits. It is also commonly used in the sheet metal and plumbing industries. Precautions that must be followed for soldering include the following:

- Parts to be soldered must have the proper fit-up so that solder can travel by capillary action along the joint. Solder will cease to flow where gaps occur in the workpiece.
- Parts to be soldered must be clean because solder will not stick to dirt, oil, or oxide-coatings on the surface. Dirt and grease can be removed with a cleaning solvent. Steel wool or an abrasive cloth is used to eliminate the oxide. Application of a flux completes the cleaning process and keeps the metal free from oxide during heating and soldering.
- Parts must be held together during soldering so there is no movement. Movement during heating causes the pieces to be misaligned. The slightest disturbance to solder causes it to solidify without forming an optimum bond, resulting in a weak joint.
- Parts to be soldered must have a suitable joint design to withstand the necessary load imposed on the joint. A lap joint is a satisfactory joint for most purposes.
- Parts must be washed in hot water after soldering to eliminate the corrosive action of the flux.

Filler Metals (Solders)

Soldering uses filler metals composed of tin, lead, antimony, and sometimes silver, and produces joints with relatively low tensile strength. Most metals such as steel, galvanized sheet steel, tin plate, stainless steel, copper, brass, and bronze can be joined with a soft solder. Tin-lead alloy solders have a melting range from about 370°F (188°C), for a mixture of 70% tin and 30% lead, to about 590°F (310°C) for a 5% tin and 95% lead mixture. See Figure 23-14.

The most common general-purpose solder is known as half-and-half or 50/50 solder. It contains 50% lead and 50% tin and melts at approximately 471°F (244°C). Alloys with a low tin content have higher melting points and do not flow as readily as high-tin alloys. Solders with a high tin content have better wetting properties and produce less cracking. Solders are available as bar, cake, solid wire, flux-core wire, ribbon, or paste. Flux-core wire solder has an acid or rosin flux in the center of the wire. With 50/50 solders, no additional flux is needed.

Special solders are available for welding aluminum and where special characteristics are required of the soldered joint. Tin-zinc solders are intended primarily for joining aluminum. A tin-antimony solder is designed to solder food-handling vessels where lead contamination must be prevented. Lead-silver solders are used for applications in which strength at elevated temperatures is required.

Flux

Just as in brazing, a flux is required for most soldering applications. The flux prevents the formation of oxides during soldering and increases the wetting action so the solder can flow more freely. General-purpose fluxes can be used on most metals.

Fluxes are classified as corrosive or noncorrosive. Rosin is the most common noncorrosive flux. Zinc chloride is the most frequently used corrosive flux. Although the corrosive types are most effective, they must be washed away from the metal after soldering. They should never be used for electrical or electronics work. Zinc chloride is prepared by adding small pieces of zinc to muriatic (commercial

Parts to be soldered must be clean and their surfaces should fit closely together.

Do not allow the parts to move during soldering while the solder is molten.

Wash the soldered work in hot water to eliminate the corrosive action of the flux.

⚠ WARNING

When diluting acid, always add the acid to the water. Pouring water into the acid may result in a violent and dangerous action.

SOLDER COMPOSITIONS AND MELTING TEMPERATURES								
Composition*					Melting Range†			
Alloy Grade	Sn	Pb	Sb	Ag	Solidus		Liquidus	
					°F	°C	°F	°C
Sn96‡	96.2	.10	.12	3.4 – 3.8	430	221	430	221
Sn95‡	95.2	.10	.12	4.4 – 4.8	430	221	473	245
Sn94‡	94.2	.10	.12	5.4 – 5.8	430	221	536	280
Sn70	69.5 – 71.5	28.5 – 30.5	.50	.015	361	183	377	193
Sn63	62.5 – 63.5	36.5	.50	.015	361	183	361	183
Sn62	61.5 – 62.5	34.5	.50	1.75–2.25	354	179	372	189
Sn60	59.5 – 61.5	39.0	.50	.015	361	183	374	190
Sn50	49.5 – 51.5	49.0	.50	.015	361	183	421	216
Sn45	44.5 – 46.5	54.0	.50	.015	361	183	441	227
Sn40-A	39.5 – 41.5	59.0	.50	.015	361	183	460	238
Sn40-B	39.5 – 41.5	59.5	.50	.015	365	185	448	231
Sn35-A	34.5 – 36.5	64.0	1.8 – 2.4	.015	361	183	447	247
Sn35-B	34.5 – 36.5	62.7	50	.015	365	185	470	243
Sn30-A	29.5 – 31.5	69.0	1.6 – 2.0	.015	361	183	491	255
Sn30-B	29.5 – 31.5	67.9	.50	.015	365	185	482	250
Sn25-A	24.5 – 26.5	74.0	1.1 – 1.5	.015	361	183	511	266
Sn25-B	24.5 – 26.5	74.2	.50	.015	365	185	504	263
Sn20-A	19.5 – 21.5	79.0	.8 – 1.2	.015	361	183	531	277
Sn20-B	19.5 – 21.5	78.5	.50	.015	363	184	517	270
Sn15	14.5 – 16.5	84	.50	.015	437	225	554	290
Sn10-A	9.0 – 11.0	89.5	.20	.015	514	268	576	302
Sn10-B	9.0 – 11.0	87.8	.50	1.7 – 2.4	514	268	570	299
Sn5	4.5 – 5.5	94.5	.50	.015	586	308	594	312
Sn2	1.5 – 2.5	97.5	4.5 – 5.5	.015	601	316	611	322
Sb5‡	94.0 min	.20	.40	.015	450	233	464	240
Ag1.5	.75 – 1.25	97.1	.40	1.3 – 1.7	588	309	588	309
Ag2.5	.25	96.85	.40	2.3 – 2.7	580	304	580	304
Ag5.5	.25	93.85	.40	5.0 – 6.0	580	304	716	380

* limits are % max. unless shown as a range or stated otherwise
† temperatures given are approximate and for information only
‡ contains less than .2% lead (Pb)

Figure 23-14. *Solders are composed principally of tin, lead, antimony, and silver.*

hydrochloric) acid until the zinc no longer dissolves. The cut, or killed, acid is then diluted with an equal quantity of water.

Joint Design and Clearance

The strength of a soldered joint depends on the design of the joint and the joint clearance. As with brazing, lap joints are the most common design, with sufficient overlap to provide the required strength. Proper joint clearance is required for maximum strength. If greater strength is needed, some type of mechanical joint should be made before soldering. A joint clearance of .003″ to .005″ is required for most applications. See Figure 23-15.

Heating Devices

In any soldering operation, both workpieces must be hot enough to melt the solder. A strong bond is achieved only if the molten solder spreads evenly over the surface. A number of devices—soldering coppers, electric soldering devices, and gas torches—are available for heating. The type used depends on the size and configuration of the assembly to be soldered. See Figure 23-16.

Soldering Coppers. A *soldering copper* is a tool that consists of a copper or steel heating tip fastened to a rod with a wooden handle. These coppers vary in size and have heads forged in several shapes. Generally, a lightweight

⚠ WARNING

When zinc is dissolved in muriatic acid, harmful chlorine fumes are given off. Preparation must always be carried out in areas with adequate ventilation. Uncut or raw acid (straight) is preferred for galvanized steel, but cut acid (diluted) may be used and is safer to handle.

Soldering Joint Designs
Figure 23-15

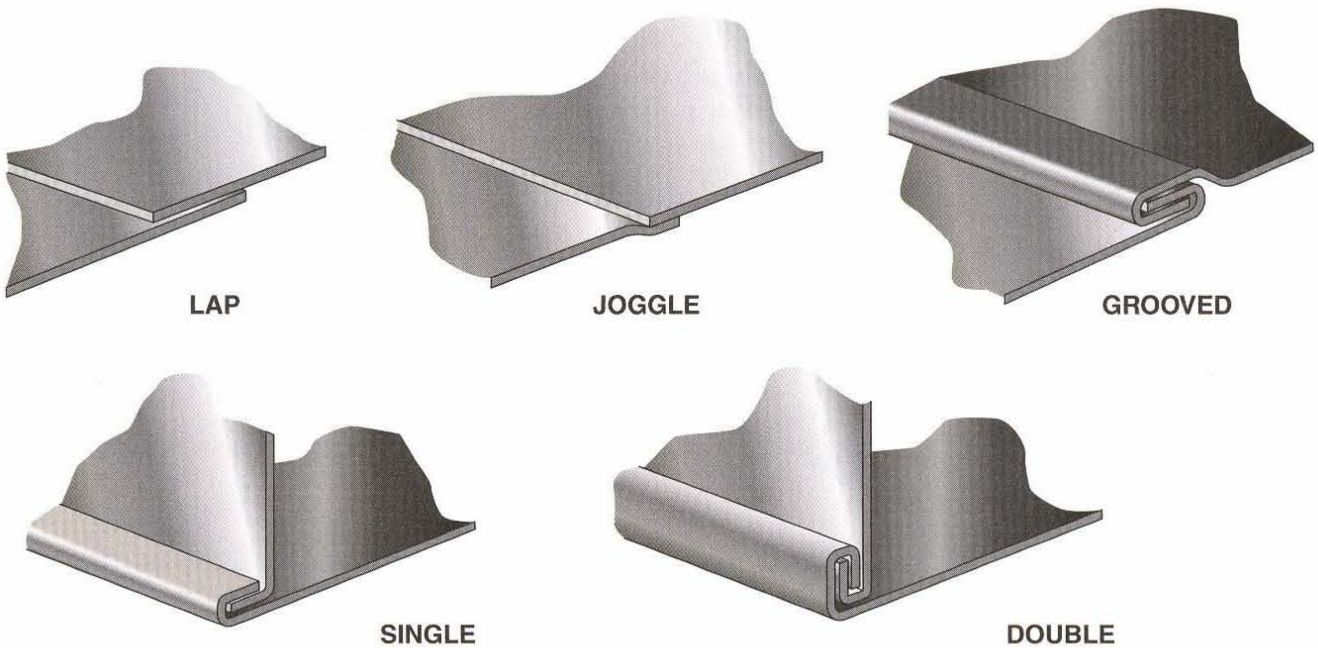


Figure 23-15. *Joint designs for soldered seams are determined by the strength requirements of the joint.*

copper is used for soldering light-gauge metal and a heavyweight copper is used for soldering heavy- gauge metal. Using a lightweight soldering copper on heavy metal does not produce enough heat to adequately heat the metal or allow the solder to flow smoothly. Soldering coppers are heated either in a furnace or with a blowtorch.

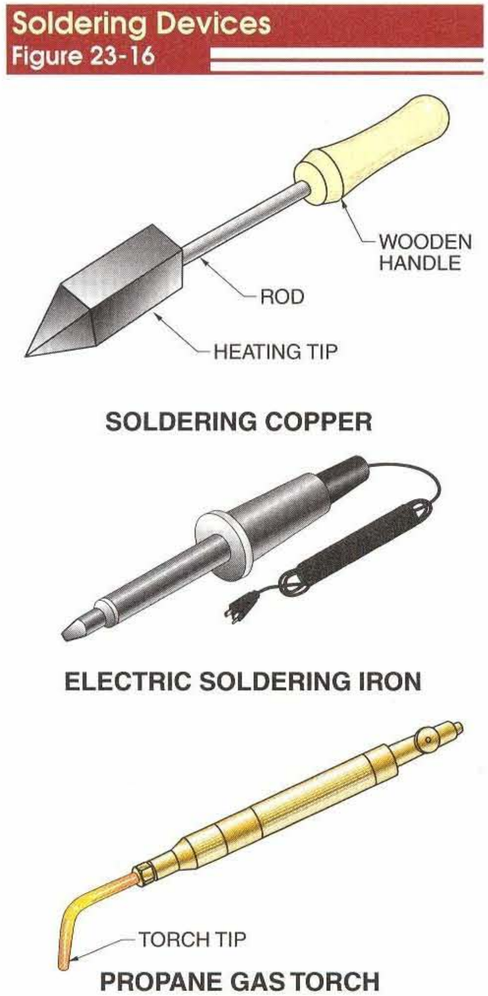
The point of a soldering copper must be covered with a thin coat of solder. Overheating or failing to keep the copper clean causes the point to become covered with oxide. The process of replacing this coat of solder is called tinning. To tin copper:

1. File each side of the point until all oxide and pits are removed.
2. Heat the soldering copper until it is hot enough to melt solder.
3. Rub the point of the soldering copper on a block of ammonium chloride (sal ammoniac) and apply solder while rubbing. Ammonium chloride helps clean the point of the soldering copper. Another method of applying solder is to dip the point of the soldering copper in a liquid or paste flux and then apply the solder.
4. Remove excess solder by wiping the soldering copper with a clean cloth.

Electric Soldering Devices. Electric soldering irons and pencils are often more convenient than soldering coppers because they maintain uniform heat. Electric soldering devices vary in size from 25 W to 550 W. Lightweight, low-voltage irons with replaceable heating elements and tips are called soldering pencils and are used for electrical and electronic work. An electric soldering gun is also very popular for electronic soldering work. Electric soldering guns produce instant heat at the tip of a long, small point when the trigger is pulled. On some soldering guns, the trigger also turns on a light, which focuses at the point.

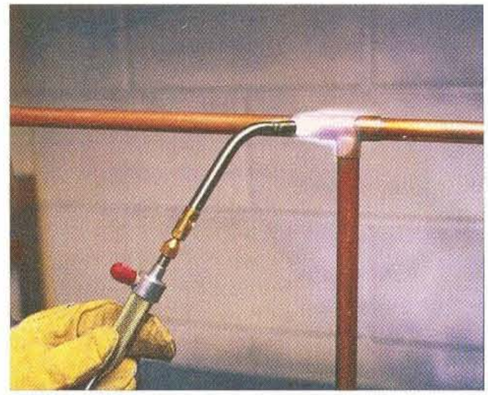
Be sure the soldering heat is adequate for the soldering job to be done.

Figure 23-16. *A number of devices are available to provide the necessary heat for soldering.*



Gas Torches. Some soldering operations are very difficult, or impossible, to perform with a soldering copper or iron. For such soldering tasks, a flame is used as the heat source. The flame can be produced with a gas torch. The gases used depend on the nature of the task. The most efficient, safe, and versatile gas torch is one that uses a variety of gases such as acetylene, MAPP, natural gas, propane, and compressed air.

A gas torch used for soldering is equipped with changeable tips that can produce a range of flame sizes. A gas-air torch has two needle valves; one valve controls the gas pressure and the other controls the compressed air. See Figure 23-17. To light a gas-air torch, the gas-needle valve is opened slightly and the gas is ignited with a sparklighter. Then the air valve is turned on and adjusted until a neutral flame results. The length of the flame is controlled by the amount of gas and air allowed to flow to the tip.



Smith Equipment

Figure 23-17. *A gas torch can be used to solder copper pipe.*

Bottled-gas torches are also used for soldering, especially when a stationary torch is not available. The bottled-gas torch must be operated with care. Follow manufacturer instructions carefully.

Soldering Techniques

The soldering technique required is determined by the size and configuration of the joint. Common manual soldering techniques are seam soldering and sweat soldering. See Figure 23-18.

Seam Soldering. In seam soldering, a layer of solder is deposited along the outside edge of the joint. To solder a seam directly, place the fluxed workpieces together and tack weld the seam in several places. Tacking is done by holding the soldering copper on the metal until the flux begins to sizzle. Apply a small amount of solder directly in front of the soldering copper point. The metal should be hot enough to melt the solder. Do not apply the solder to the soldering copper. Once the workpiece is tack welded, start at one end of the seam and heat the metal. Apply solder as needed in front of the soldering copper point. If necessary, press each newly soldered section together.

Soldering Techniques
Figure 23-18

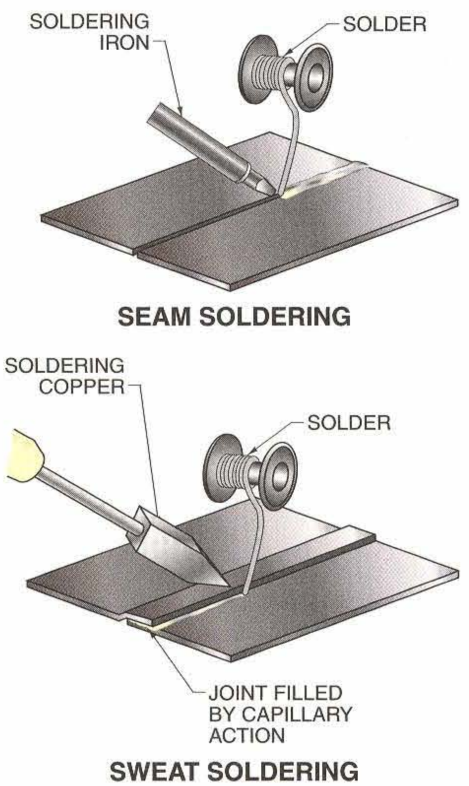


Figure 23-18. *In seam soldering, a layer of solder runs along the outside edge of the joint. In sweat soldering, two pieces are joined without any solder being visible.*

Sweat Soldering. *Sweat soldering* is a process whereby two surfaces are soldered together without allowing the solder to be seen. To perform sweat soldering, follow the procedure:

1. Coat the workpiece to be soldered with flux after all dirt, oil, grease, and oxide have been removed.
2. Apply a uniform coating of solder to each of the surfaces to be joined.
3. Place the surfaces together with the soldered sides in contact.
4. Place the flat side of a heated copper on one end of the seam. To avoid smearing the exposed surfaces of the metal with solder, remove any excess solder on the copper by quickly wiping the point with a damp cloth before placing it on the joint.
5. As the solder between the two surfaces begins to melt and flow out from the edges, press down on the metal with a punch. Draw the copper slowly along the seam and follow with the punch. Do not move the copper faster than the solder melts.

Inspecting Soldered Joints

Soldered joints may be visually inspected for quality as follows:

- Joint integrity. Joint should be smooth, with no porosity. A smooth transition should exist between the soldered joint and the base metals.
- Non-wetting and de-wetting. Nonwetting occurs when the solder fails to wet the metal, which retains its original color. De-wetting occurs when solder flows across the metal, but is pulled back into globules, leaving a dirty, discolored-looking surface. Both are indications of improper precleaning or flux selection.
- Overheating or underheating. Overheating is exhibited by burned fluxes and oxides on the solder joint. 7 is exhibited by poor flow of solder into the joint. They are both indicative of poor bonding between the solder and the joint.

POINTS TO REMEMBER

Brazing

1. Use the lowest effective brazing temperatures to minimize grain growth, warpage, and hardness reduction.
2. Joint design for brazing is based on the adhesive qualities of the filler metal and on joint clearance.
3. Surfaces to be brazed must be completely free of oil, grease, dirt, and oxide.
4. Always use an appropriate filler metal and flux that is recommended for the metal to be brazed.
5. When using oxyacetylene or MAPP-oxygen gas mixtures, heat the surfaces with the outer envelope of the flame and not the inner cone.
6. Remove all flux residue after the brazing operation is completed.

Braze Welding

1. Use a qualified procedure for braze welding.
2. Clean surfaces thoroughly before applying the filler metal.
3. Be sure the surfaces are properly tinned before depositing beads.
4. Use a neutral flame unless otherwise specified. Use a circular torch motion.
5. Do not braze weld a metal that will be subjected to high temperatures or high stresses.

Soldering

1. Parts to be soldered must be clean and their surfaces should fit closely together.
2. Do not allow the parts to move during soldering while the solder is molten.
3. Wash the soldered work in hot water to eliminate the corrosive action of the flux.
4. Be sure the soldering heat is adequate for the soldering job to be done.

QUESTIONS FOR STUDY AND DISCUSSION

1. Why is a lap joint better than a butt joint for brazing?
2. Why is joint clearance an important factor in brazing?
3. What procedure should be used in cleaning surfaces to be brazed?
4. Why is a flux needed for brazing?
5. Why should all flux residue be removed after brazing is completed?
6. What do the AWS classification symbols for brazing filler metal represent?
7. How should the torch flame be applied to the work to carry out a brazing operation?
8. What is meant by liquidus and solidus temperatures?
9. What is the difference between braze welding and brazing?
10. What are some of the advantages of braze welding?
11. When should braze welding not be used?
12. What kind of filler metal is needed for braze welding?
13. How should flux be applied?
14. When is a surface hot enough for braze welding?
15. During the soldering process, why should parts be held firmly in place?
16. What is meant by tinning copper?
17. How does seam soldering differ from sweat soldering?

Surfacing 24

Other Welding Processes

Surfacing is one of the most economical methods of extending the life of machine parts, tools, and construction equipment. The surfacing process applies a hard, wear-resistant layer of material to surfaces or edges of worn-out parts. The process may involve building up worn shafts, gears, or cutting edges of tools. Many types of wear can be corrected with surfacing.

Surfacing can be applied by welding or thermal spraying. Surfacing can correct many types of abrasion, erosion, adhesion, and surface fatigue problems. Arc welding processes used to apply weld overlays include SMAW, GTAW, GMAW, PAW, and SAW; OAW can also be used. Thermal spraying methods used to apply weld overlays include plasma spraying, flame spraying, high-velocity oxyfuel (HVOF) flame spraying, spray and fuse, and arc spraying.

SURFACING

Surfacing is the application of a layer or layers of material to a surface to obtain desired properties or dimensions. Surfacing is used on new components and for repairs. Surfacing may also be used to correct improper joint preparation and poor joint fit-up.

When designing new components, surfacing is used if the expected wear is concentrated to a small area that can be welded. When a welding process is used for surfacing, the surfacing material must create a metallurgical bond with the base metal. *Metallurgical bond* is the joining of two components by atomic fusion. Depending on the weldability of the base metal, preheating, interpass temperature control, and postheating may be required.

When used for repair work, surfacing helps retain the ductility of the base metal, while providing a surface resistant to abrasive wear. See Figure 24-1. Surfacing to improve wear resistance is also known as hardfacing. Surfacing for corrosion resistance is used if mechanical rebuilding or replacement of the part is not cost-effective, and if plating is not an effective method of restoring dimensions.

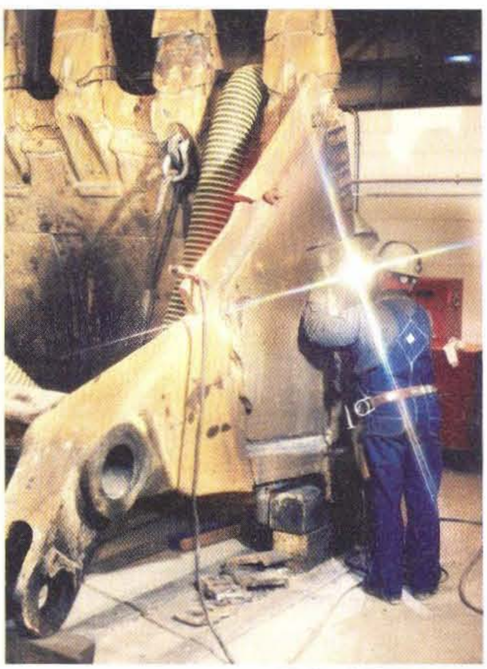


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Figure 24-1. *Surfacing is used on heavy equipment to retain the ductility of the base metal, while providing a surface resistant to abrasive wear.*

With surfacing welds, the surfacing material creates a metallurgical bond with the base metal. With thermal spray coating, the bond is mechanical.

Surfacing need only be applied to surfaces that may wear excessively if not protected. Contact surfaces, screw flight edges, journal bearings, seal-wiped areas, hammer tips, and shear edges are some examples. Sections of a component that do not wear do not require surfacing. On shovel or bucket teeth and items subject to heavy wear, surfacing creates regions that allow abrasive material to become trapped so that the abrasive material becomes a wear surface against itself.

The area and thickness of the applied surfacing must be minimized to reduce distortion. With high hardness deposits, it is usually not possible to apply more than two layers without cracking. If the desired thickness of the hard material is inadequate, a soft metal buildup is used to minimize cracking before the final hard deposit is applied.

WEAR TYPES

Materials and parts in service may be subjected to many types of wear. Most wear can be repaired by surfacing; however, not every type of surfacing process may be applied to every type of wear. The specific wear type must be determined before specifying a surfacing method.

Wear types that materials and parts in service may be subjected to are erosion (low-stress abrasion), gouging (high-stress abrasion), solid particle impingement, liquid impingement, cavitation, slurry erosion, fretting, adhesive wear and galling, pitting and spalling, impact damage, and brinelling.

Erosion (low-stress abrasion) is a form of abrasive wear in which the force of an abrasive against the surface causes the removal of surface material.

Erosion (Low-Stress Abrasion)

Erosion (low-stress abrasion) is a form of abrasive wear in which the force of an abrasive against the surface causes the removal of surface material. The forces are low, resulting in the removal of small particles and little breakdown of the abrasive body. Erosion can occur in moving liquids containing abrasive particles. If the liquid is corrosive, the form of damage is erosion-corrosion.

Areas in which erosion can occur include coal and ore chutes, and slurry pipelines. Welding and thermal spray coating may be used to combat erosion.

Gouging (High-Stress Abrasion)

Gouging (high-stress abrasion) is a severe form of abrasive wear in which the force between an abrasive body and the wearing surface is large enough to macroscopically gouge, groove, or deeply scratch the surface.

An example of gouging is the action of backhoe teeth against a surface. Welding may be used to combat gouging. Thermal spray coating should not be used because the abrasive forces are typically too strong for thermal spray coating to withstand.

Solid Particle Impingement

Solid particle impingement is wearing away of a surface by repeated impact from solid particles. Solid particle impingement forms small craters and removes tiny chips from the surface.

Solid particle impingement occurs in abrasive blasting or cyclone separators. Both welding and thermal spray coating may be used to fight solid particle impingement erosion. The angle of impact of the particle and its hardness affects which process should be used for surfacing.

Liquid Impingement

Liquid impingement is progressive material removal from a surface by the striking action of a liquid. The removal of material may be aggravated by corrosive liquids. Liquid impingement occurs in steam turbine vanes and fans that exhaust liquid droplets.

Both welding and thermal spray coating may be used to fight liquid impingement. The corrosiveness of the liquid may influence the surfacing process used. When liquid impingement is caused by liquid droplets, a rubber lining may be used because it provides better protection from repeated impact without damage.

Cavitation

Cavitation is surface damage caused by collapsing vapor bubbles in a flowing liquid. The vapor bubbles form because of changes in flow velocity and/or direction, or a reduction in the cross section of the flow passage. An increase in pressure at a location causes the bubbles to collapse. The collapsing bubbles give rise to shock waves or minute explosions that cause contact stresses on the metal surface. Repetitive shock waves or explosions lead to spalling and pitting of the surface.

Cavitation is common in pumps and engine cylinders and can occur in ship propellers, pump impellers, and casings. Welding may be used to combat cavitation. Thermal spraying should not be used.

Slurry Erosion

Slurry erosion is the progressive loss of material from a surface caused by slurry moving over the surface. *Slurry* is a mixture of solid particles in a liquid. If the slurry is corrosive, erosion of material from the base metal is accelerated.

Areas in which slurry erosion can occur include slurry pipelines and pumps, and oil well downhole equipment. Welding and thermal spray coating may be used to combat some types of slurry erosion. When slurry is corrosive, the surfacing material must provide corrosion resistance.

Fretting

Fretting is surface damage between two materials, usually metal, caused by oscillatory movement between the surfaces. Fretting produces oxide debris and leads to pitting and, eventually, fatigue failure.

Fretting commonly occurs on bolted components subjected to repetitive stresses, and can occur in loose-fitting bearings; metal parts in vibrating contact; and gears and sheaves at the setscrews. Welding and thermal spray coating may be used to combat fretting.

Adhesive Wear and Galling

Adhesive wear is the removal of metal from a surface by welding together and subsequent shearing of minute areas of two surfaces that slide across each other under pressure. In advanced stages, adhesive wear leads to galling.

Adhesive wear is the removal of metal from a surface by welding together and subsequent shearing of minute areas of two surfaces that slide across each other under pressure.

Adhesive wear may occur in drive chains, gears, and bushings. Welding may be used to combat adhesive wear; selection of weld overlay consumables is on a trial-and-error basis, or repeated, successful experience. Thermal spraying should not be used.

ASI Robicon

Conveyor systems are exposed to many types of wear including fretting, which results from repetitive stresses, and adhesive wear, which results from parts sliding across each other.

Galling is a condition that occurs when excessive friction, caused by rubbing of high spots on the surface, results in localized welding with subsequent spalling (formation of surface slivers) and further roughening of the rubbing surfaces. Galling is a result of an improper mating combination between components, and not a failure of any one component. Galling may result in seizure of a component.

Examples of components that gall include valve trim, engine camshafts, and threaded connections. Galling may be combated using welding. Thermal spraying should not be used.

Pitting (Spalling)

Pitting or spalling is the forming of localized cavities in metal resulting from corrosion, repetitive sliding or rolling surface stresses, or poor electroplating.

Pitting (spalling) is the forming of localized cavities in metal resulting from corrosion, repetitive sliding or rolling surface stresses, or poor electroplating. Pitting leads to subsurface fatigue cracking. Pitting appears on the surface as cavities, depressions, or flakes.

Pitting can occur in cam paths, gear teeth, rolling element raceways, and sprockets. Welding may be used to combat pitting or spalling, but the type of material used must be carefully selected. Thermal spraying should not be used.

Impact Damage

Impact damage is removal of material from and damage to a surface caused by repetitive collisions or impact between two surfaces. Impact damage can occur in hammerheads, riveting tools, and pneumatic drills. Welding may be used to minimize impact damage. Thermal spraying should not be used.

Brinelling

Brinelling is localized plastic deformation or surface denting caused by repeated local impact or overload. Brinelling occurs in wheels or rails, rolling element bearings, and cams. Welding may be used to combat brinelling. Thermal spraying should not be used.

SURFACING METHODS

Surfacing methods used to repair and combat wear are welding and thermal spraying. See Figure 24-2. Spray and fuse is a surfacing variation that combines traits of both welding and thermal spraying. Surfacing by welding creates fusion with the base metal. Surfacing by thermal spraying applies a coating to a surface that is mechanically bonded to the base metal and does not fuse with it. Spray and fuse is a method of improving wear or corrosion resistance that includes elements of both surfacing weld and thermal spraying. Many consumables can be used for weld overlay and thermal spraying, but a few consumable types are most often used to correct most wear problems.

Welding

Weld overlay is the application of surfacing using a welding process that creates a metallurgical bond with the base metal through melting of the surfacing metal.

Welding processes are commonly used to apply a weld overlay to produce the desired properties on the surface of the metal. *Weld overlay* is the application of surfacing using a welding process that creates a metallurgical bond with the base metal through melting of the surfacing metal. Welding is also used to apply wear-resistant or corrosion-resistant alloys as an overlay to the surface of a metal. Weld overlay can only be used on metal combinations that can be joined by welding.

Only the second layer of a weld deposit provides the intended wear properties because the first layer is diluted by the base metal. *Dilution* is a change in the composition of welding filler metal in the weld deposit caused by melted base metal. The amount of dilution varies depending on the welding process used. See Figure 24-3.

WEAR TYPES AND SURFACING OVERLAY METHODS...			
Wear Type	**Description**	**Examples**	**Surfacing Methods**
Erosion (Low-Stress Abrasion)	• abrasive forces result in scratching of the surface • low force, does not crush abrasives	• particles sliding in chutes • packing cartons that run on shafting • sandy soil being plowed • abrasive material being cut	• welding • thermal spraying
Gouging (High-Stress Abrasion)	• abrasive forces result in deep scratches • surface has insufficient compressive strength to resist damage • plastic deformation • chip removal after repeated compressive loading	• rollers running on dirty tracks • ball mills for grinding minerals • farm implements in hard soil • heavily-loaded metal sliding systems in dirty environments • gyratory crusher parts • hammer mill hammers • jaw crushers	• welding
Solid Particle Impingement	• wearing of surface caused by repeated impact of solid particles • forms small craters • removes chips of material	• abrasive blasting • aircraft operating in sand or dirt • cyclone separators	• welding • thermal spraying
Liquid Impingement	• progressive material removal caused by the striking action of liquid	• steam turbine vanes • fans exhausting liquid droplets	• welding • thermal spraying • rubber lining
Cavitation	• progressive loss of material caused by air bubbles of a liquid collapsing near surface	• ship propellers • pump impellers and casings • ultrasonic cleaners	• welding
Slurry Erosion	• progressive loss of material caused by a slurry	• slurry pipelines and pumps • oil well downhole equipment • mud pumps • well pumps • agitators	• welding* • thermal spraying*
Fretting	• oscillatory movement with little displacement • produces oxide debris • leads to pitting and fatigue failure	• gears and sheaves held on shafts with setscrews • bearings loose-fitting on shafts • drive coupling components • metal parts in vibrating contact • bolted components subjected to repetitive stress	• welding • thermal spraying
Adhesive Wear or Galling	• localized damage in solid-state welding between sliding surfaces leading to material transfer between surfaces	• face seals • gears • bushings • drive chains • actuators	• welding†
		• heavily loaded sliding members • austenitic stainless steel gate valves • plug valves • threaded fastener assemblies	• welding

* when slurry is corrosive, must have adequate corrosion resistance
† determine proper consumable by trial & error

Figure 24-2...

... WEAR TYPES AND SURFACING OVERLAY METHODS			
Wear Type	**Description**	**Examples**	**Surfacing Methods**
Pitting (Spalling)	• removal or displacement of a surface • caused by repetitive sliding or rolling surface stresses • leads to subsurface cracking	• cam paths • gear teeth • rolling element raceways • sprockets	• welding
Impact Damage	• removal of material from a surface • caused by repetitive impact collisions of two surfaces	• hammerheads • riveting tools • pneumatic drills	• welding
Brinnelling	• localized plastic deformation or surface denting • caused by repeated local impact or overload	• wheels or rails • rolling element bearings and cams	• welding

Figure 24-2. *Parts in service are commonly subjected to four types of wear: abrasion, erosion, adhesion, and surface fatigue. Surfacing overlays to repair wear can be applied by welding and thermal spraying.*

Dilution
Figure 24-3

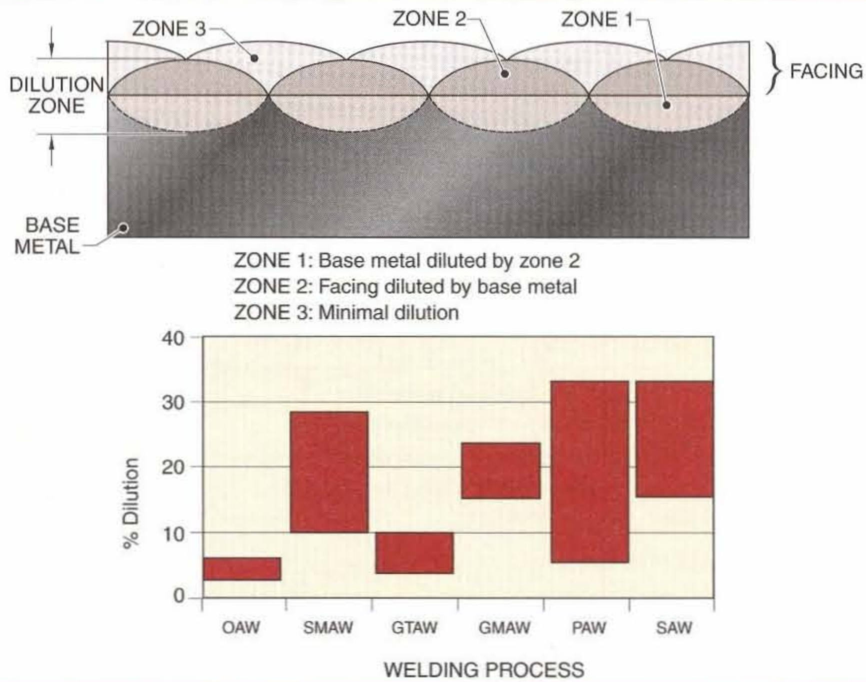

Figure 24-3. *Dilution varies with the type of welding process used for surfacing.*

Weld overlay may be applied using the OAW, SMAW, GTAW, GMAW, SAW, or PAW processes.

Dilution is generally a reduction in the alloy content of the weld deposit since the melted base metal, with lower alloy content, is incorporated into the melted filler metal, changing the composition of the deposited metal.

A one-layer deposit may be possible if it is carefully applied by the welder and if a welding process that causes little melting of the base metal, such as OAW, is used. Weld overlay may be applied using OAW, SMAW, GTAW, GMAW, SAW, and PAW processes.

OAW Weld Overlays. An OAW weld overlay is widely used on steels where maximum hardness and minimum crack susceptibility are required. An OAW weld overlay can be applied to most materials, except for copper alloys.

The base metal surface must be preheated to produce a sweating condition on the surface. During preheating, the tip of the surfacing filler metal is held on the fringe of the flame until the metal has been sufficiently heated. The filler metal is then moved into the center of the flame and melted. Filler metal is deposited using a regular forehand welding technique with a slight weaving motion. Generally, a slightly reducing flame is recommended, as this adds carbon to the deposit. Filler metal used for OAW weld overlay should be composed of low-melting-point, high-carbon metal.

The deposition rate with OAW is not as high as with other processes; however, OAW minimizes fusion of the base metal. The reduced fusion of the base metal minimizes dilution and loss of hardness of the surfacing alloy. OAW is not used for copper alloys because with copper a greater loss of aluminum or silicon by oxidation occurs compared with arc welding processes, resulting in a softer deposit.

The absence of steep thermal gradients in OAW reduces cracking or spalling of the weld overlay because thermal stresses are reduced. OAW weld overlays are a useful technique for depositing weld overlays on small parts such as engine valves, plowshares, and tools. One layer may be sufficient.

SMAW Weld Overlays. Weld overlays are commonly applied using SMAW because of its high deposition rate and relatively low dilution. It also is widely used for surfacing large areas or for heavy parts that normally would require excessive time to heat with an oxyacetylene flame. SMAW weld overlays are especially suitable for manganese steel and other steel alloys where heat buildup must be restricted.

The surface of the base metal must be thoroughly cleaned before surfacing; however, cleanliness in SMAW is not as stringent as in other processes. Although some porosity and cracking may be present, such discontinuities are usually acceptable in the severe types of applications for which SMAW is used. These severe applications, such as earth moving equipment and mining equipment, require thick overlays. It is generally necessary to apply several layers of surfacing to achieve the intended surface hardness. See Figure 24-4.

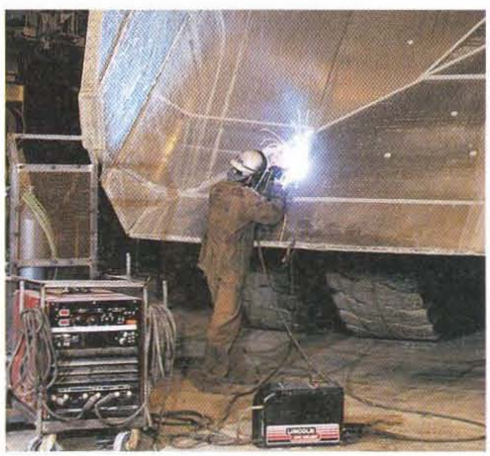

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Figure 24-4. *Surfacing of earth moving equipment is performed using weld overlay. Several layers are typically added to achieve the intended surface hardness.*

Either AC current or DC current can be used to produce a satisfactory weld overlay. To properly apply weld overlay using SMAW, follow the procedure:

1. Remove all rust, scale, and other foreign matter from the surface.
2. Set current just high enough to provide sufficient heat to maintain the arc yet prevent dilution.
3. Position the workpiece so the section to be surfaced is in flat position. Most surfacing electrodes are designed for use in flat position only.

Use a minimal amount of heat when surfacing with SMAW.

When applying a weld overlay with SMAW, maintain a medium arc length and do not allow the electrode coating to contact the base metal.

When depositing surfacing material, remove slag after each pass.

4. Maintain a medium arc length and do not allow the electrode to touch the base metal.

   When making the deposit, use a straight or weaving motion. A weaving or whipping motion should be used on thin metals. A weaving motion is preferred when only a thin bead deposit is required. The width of the weaved bead should not be more than ¼″.

   A whipping action is often used when surfacing an area along a thin edge. The arc is held over the heavy portion and then whipped out to the thin edge. In this manner, a shallow deposit is made before the heat builds up enough in the base metal to burn through.
5. Remove slag from the surface after each pass.
6. Manipulate the electrode carefully to secure adequate penetration into previous passes. Hold the electrode over the deposited bead momentarily to allow heat to build up in the adjoining beads. This procedure also minimizes undercutting.

GTAW and GMAW Weld Overlays

Both GTAW and GMAW are ideal for applying weld overlays. Surfacing materials are easily deposited to form a smooth, uniform, porosity-free weld overlay. When using GTAW and GMAW for weld overlay, prevent dilution of the deposited weld metal as dilution reduces the effectiveness of the weld overlay. The shielding gas required by GTAW and GMAW prevents oxidation and the loss of alloying ingredients when performing aluminum and bronze surfacing. Surfacing with GTAW is somewhat slower than hardfacing with GMAW, but the resulting weld overlay is of slightly higher quality.

GTAW produces a clean deposit with a high rate of deposition. However, the high heat input results in steep thermal gradients, causing dilution and loss of hardness in the weld overlay coupled with increased cracking susceptibility from high thermal stresses. GTAW is often used where thin overlays are required. GTAW is particularly effective in applying cobalt-base alloys.

Surfacing with GTAW ordinarily requires very little preheating. Since the heat buildup is minimal, there is less distortion and very little of the base metal is affected by the heat of welding.

GMAW is not as widely used for surfacing as the other arc welding processes. However, with its continuous wire feed, GMAW is faster than GTAW and produces excellent weld overlays. GMAW also allows for high deposition rates and low dilution of the surfacing.

A variety of special filler metals are available for practically every surfacing operation. Composite filler metal is typically used. Composite filler metals, such as flux-cored electrodes, consist of a tubular steel shell with metallic powders or fine particles of hard compounds incorporated into the center or into the coating.

PAW Weld Overlays

Application of weld overlay using PAW is a mechanized GTAW process that uses a metal powder as the surfacing material. The metal powder is carried from a hopper to the electrode holder in an argon gas stream. From the torch, the powder moves into the arc stream where it is melted and then fused to the base metal. Plasma arc welding (PAW) is a welding process that uses a constricted arc between a nonconsumable tungsten electrode and the weld pool, it is not a metal spray process. See Figure 24-5.

A variety of cobalt, nickel, and iron-base surfacing powders are available. These powders are fused materials and, consequently, are homogeneous in

composition. They are classified as high-alloy materials and have varying degrees of impact-resistance, abrasion-resistance, and corrosion-resistance. The surfacing application required should be determined before selecting the metal powder to be used.

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Figure 24-5. *PAW surfacing is a welding process that uses a tungsten electrode and metal powder.*

The power source used for PAW weld overlays consists of a conventional DCEN power supply unit. A second DC unit is connected between the tungsten electrode and the arc-constricting orifice to support a nontransferred arc. The second power supply supplements the heat of the transferred arc and serves as a pilot arc to start the transferred arc. Argon gas is used to form the plasma as well as the shielding.

SAW Weld Overlays

Submerged arc welding (SAW) is a welding process that uses an arc between a bare metal electrode and the weld pool. The SAW process is used when surfacing an extensive area, and on parts that require heavy deposits of surfacing. Since SAW uses a high welding current, it has a high deposition rate and results in high quality deposits.

Filler metal may be either solid or tubular. Filler metal is especially suitable for surfacing that requires high compression strength. However, the relatively deep penetration of the submerged arc weld with its protective flux covering usually develops intense heat in the weld area. Greater precautions must be taken to provide suitable preheat and postheating for stress relief.

Very often, the full strength of the surfacing material is attained only by depositing two or more layers. With SAW, the initial weld layer frequently becomes diluted when fused into the base metal and an additional layer is usually necessary to ensure the desired surface.

Surface Preparation

Base metal preparation for weld overlay depends on the required quality of the finished surface. For dirty work, such as guide plates, coke chutes, or power shovels, where some degree of surface porosity or inclusions may be tolerated, loose scale, dirt, or other foreign substances should be removed by wire brushing, grinding, or sandblasting.

For critical work such as valve seats, pump shafts, or coating rolls where no porosity or inclusions are permitted, the base metal must be prepared by machining or grinding to bright metal; otherwise, surface irregularities can lead to gas voids and inclusions. All foreign matter such as grease, oxides, or dirt must be removed completely. The surface may also be scrubbed with methanol. Handling of the component after preparation should be minimized because even fingerprints can interfere with good wetting action during surfacing.

Weld Overlay Filler Metals

Filler metals used for weld overlay are formulated to possess properties that provide wear resistance or corrosion resistance to the surface. Filler metals may be bare metal or wire; coated electrode; flux-cored electrode; metal powder; or metal-cermet, self-fluxing powder. See Figure 24-6.

WELD OVERLAY FILLER METALS			
Material	**Designation**	**Rockwell Hardness C Scale (HRC)**	**Application**
High speed Steel	R Fe 5-B OR E Fe 5-B	60	• repairs on tool steels
High Chromium Iron Alloy	R Fe Cr-Al OR E Fe Cr-Al	58	• high-stress abrasion resistance for – heavily-loaded metal – metal sliding systems in dirty environments
Nickel Alloy	R Ni Cr-C OR ENi Cr-C	35–56	• low-stress abrasion resistance • metal-to-metal wear • deposits that must be machined – shafts – running in packing – ash handling equipment
Cobalt Alloy	RCo Cr-A OR ECo Cr-A	38–47	• metal-to-metal wear • low-stress abrasion resistance • elevated temperatures • corrosive environments
Composite material	RWC 20/30 OR EWC 20/30	60	• high-stress and gouging abrasion resistance for – crushers – earth-moving equipment

Figure 24-6. *Filler metals may be bare metal or wire; coated electrode; flux-cored electrode; metal powder; or metal-cermet, self-fluxing powder.*

Filler metals may be bare metal or wire; coated electrode; flux-cored electrode; metal powder; or metal-cermet, self-fluxing powder.

AWS specifications identify filler metals for surfacing applications. The AWS designation uses chemical symbols to describe the main elements, such as RNiCr-A. An R prefix stands for bare wire or rod, which does not normally conduct current. An E prefix stands for electrode, which can conduct current. The A, B, and C suffixes identify a specific alloy within the group. The type of filler metal used depends on the requirements of the weld metal applied. AWS specifications do not encompass most tool steel and alloy steel filler metals used for surfacing; trade names are used instead.

Thermal stresses may develop in a surfacing deposit as it contracts during cooling. Coupled with constraint and the limited ductility of some filler metals, cracking of the deposit may result. Preheating the base metal helps minimize cracking, and in some cases hardness of the deposit may be compromised to reduce cracking. In most surfacing deposits (except those used for sealing purposes), some cracking is expected and is of little concern.

Thermal Spraying

Thermal spraying (*THSP*) is a group of processes in which finely divided metallic or nonmetallic materials are deposited in a molten or semimolten condition to form a coating. The thermal spray coating material may be a powder, ceramic, rod, or wire.

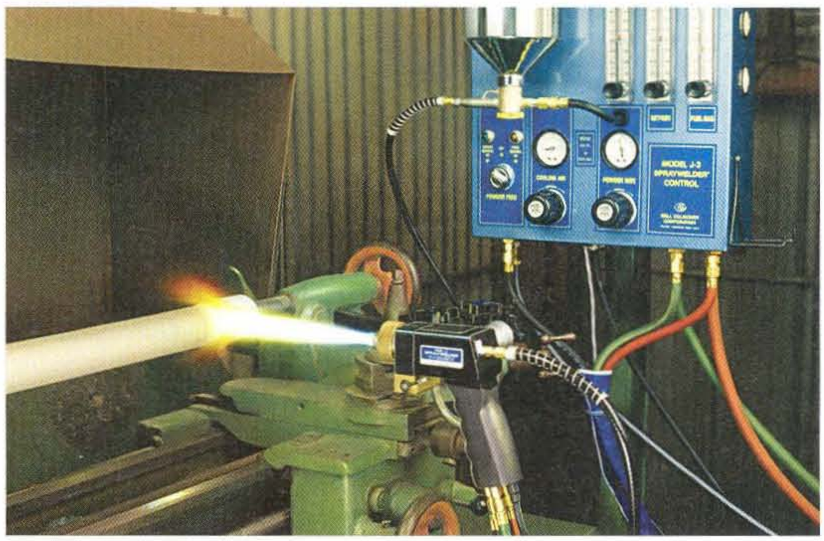
The most important aspect of thermal spraying is correct preparation of the component. It must be cleaned and roughed, but sharp corners should be avoided. Some preheating may be necessary depending on the alloy content of the component. Spraying should be performed immediately after the component is cleaned. If the component is not sprayed immediately, it should be protected from the atmosphere by wrapping it in paper containing a vapor-phase corrosion inhibitor.

The first pass should be applied as soon as possible after the part is prepared and as quickly as possible. Additional coats may be applied more slowly. The surface of the component does not heat up appreciably during thermal spraying as it does during welding but a uniform temperature must be maintained throughout the component during surfacing. Distortion during thermal spraying is minimal.

Thermal spraying is done with a special spray gun and, typically, 20 gauge to 3/16″ diameter wire. Spray guns can spray about 4 lb to 12 lb of metal per hour. Larger guns are usually mounted on a fixture and are designed for spraying large machine components.

A thermal spray gun consists of two major parts: the power unit and the gas head. The power unit feeds the coating material into the nozzle of the gun. The nozzle has a center orifice through which the coating material is fed. Around the orifice are a number of gas jets that provide the flame and the air stream. As the coating material comes through the orifice, it is melted and atomized by the flame. The gas head controls the flow of oxygen, fuel gas, and compressed air. The fine molten particles are picked up by the air stream and projected against the work.

A hopper mounted on the torch body feeds powdered coating material (metal alloy) into the gas stream while the operator controls the flow of the powdered alloy. The alloy particles become molten as they are sprayed through the flame and onto the workpiece. See Figure 24-7.



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Thermal spraying is commonly used to build up shafts.

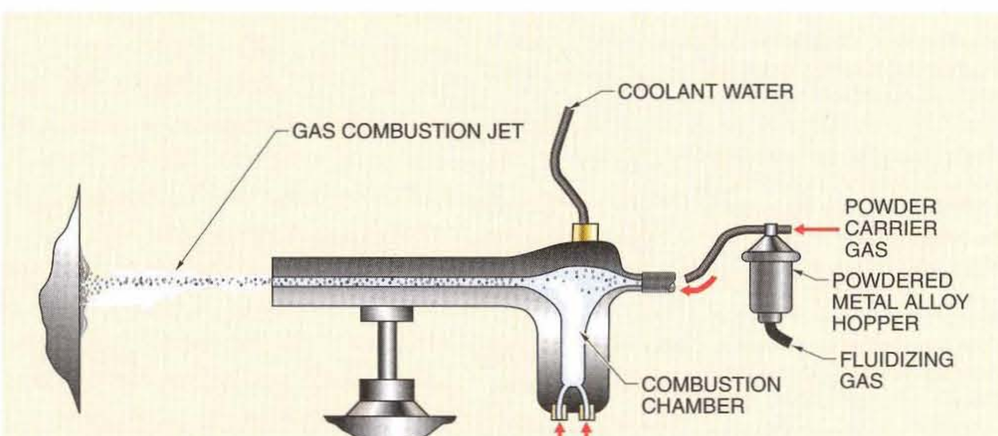

Figure 24-7. *An oxyacetylene metal spray torch has a mounted hopper that feeds powdered metal alloy into the gas stream. The metal particles melt as they are sprayed through the flame and are fused to the workpiece.*

The most commonly used gas for the oxyfuel flame is acetylene, which is capable of producing temperatures exceeding 5600°F (3094°C). Hydrogen or propane may be used for metals that melt at a lower temperature. Thermal spraying processes include plasma spraying, flame spraying, high-velocity oxyfuel (HVOF) flame spraying, spray and fuse, and arc spraying. See Figure 24-8.

Plasma Spraying. *Plasma spraying* is a thermal spraying process in which a plasma torch is used as a heat source for melting and propelling the surfacing material to the workpiece. Plasma spray is the most commonly used form of thermal spraying. Plasma spray uses a confined high-current electric arc and an inert gas such as argon to produce a high-pressure stream of hot ionized gas called plasma.

The gas is directed through the nozzle and an arc is struck between the electrode and the nozzle. As the gas passes through the arc, it is ionized, forming a stream of plasma with temperatures that reach as high as 30,000°F.

A coating material is fed into the plasma stream, melted, and is propelled to the workpiece at approximately 400 feet per second (fps). Coatings applied by the plasma spray method are denser, but more costly, than those applied by flame spraying. See Figure 24-9.

⚠ WARNING

Ventilation is necessary to remove dust particles and fumes that are extremely hazardous to an operator's health. If positive ventilation is not possible, the operator should wear a respirator.

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Figure 24-9. *In plasma spraying, an argon gas stream carries the metal powder surfacing material from a hopper to the electrode holder. The powder moves into the arc stream, is melted, and fuses to the base metal.*

THERMAL SPRAYING PROCESSES

Process	Method	Bond Strength*	Porosity†	Cost
Plasma Spraying	Powder is fed into plasma created by striking an arc in an inert gas and then propelled toward the workpiece with compressed air	430–1000	5	Mid-range
Flame Spraying	Consumables in the form of rod, wire, or powder are heated in an oxyacetylene flame, and propelled toward the workpiece	600–1000	10–20	Low
High-Velocity Oxyfuel (HVOF) Flame Spraying	Hot gas from fuel combustion melts powder that is directed toward the workpiece at extremely high velocity	> 10,000	< 5	High
Spray and Fuse	As in flame spraying but powdered nickel or cobalt alloy is used that is fused to the workpiece by torch or furnace heating after spraying, creating a nonporous surface	600–1000	0	Mid-range
Arc Spraying	Two consumable wires of coating materials are melted by an electric arc, atomized, and propelled toward the workpiece with compressed air	600–1000	5	Mid-range

* in psi
† in %

Figure 24-8. *Thermal spraying processes include plasma spraying, flame spraying, high-velocity oxyfuel (HVOF) flame spraying, spray and fuse, and arc spraying.*

The temperature for plasma spraying is much higher than that of flame spraying and coating materials that have high melting points can be applied using plasma spraying. Most inorganic materials that melt without decomposition can also be used.

The coating material to be sprayed is a powder that is suspended in a carrier gas and carried to the plasma spray gun. The high-temperature plasma immediately melts the powdered metal and propels it to the surface of the workpiece.

Since inert gas and high gas temperatures are used, the mechanical and metallurgical properties of the coatings are generally superior to either type of flame spraying, and bond and tensile strengths are higher.

Flame Spraying. *Flame spraying* is a thermal spraying process that uses an oxyfuel gas flame as a source of heat for melting the coating material. Two variations of flame spraying exist. One uses metal in wire form and is sometimes referred to as metallizing. The other uses materials in powder form. In both variations, the coating material is fed through a gun and a nozzle and melted in the oxyfuel gas flame.

Flame spraying can be applied manually or automatically. Flame spraying allows hard, thin coatings to be deposited quickly and uniformly. Deposits range from .01″ (.25 mm) to .08″ (2 mm) thick. The coatings are porous and usually brittle. They do not resist excessive mechanical abuse.

A wire, powder, or rod coating material is introduced into a stream of fuel gas, usually oxygen and acetylene, which atomizes the material, allowing it to be propelled by a stream of air to the surface. Compressed air is used for atomizing and propelling the material to the workpiece. A torch is used with the proper flame setting, and the trigger is pressed to propel the material to the surface. See Figure 24-10.

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Figure 24-10. *In flame spraying, a torch is used with the proper flame setting, and a trigger is pressed to propel the coating to the surface.*

Wire spray materials are metals that can be made into flexible wire that will melt in an oxyacetylene flame. Wire spray materials are commonly zinc, aluminum, carbon steel, 300 series stainless steel, bronze, or molybdenum. Flame spraying with wire spray materials is used to coat metals for rust protection, for heavy rebuilding, or to restore dimensions. It is not used on parts that are subject to rigorous service conditions.

Powder spray materials include carbides, high-alloy steels, stainless steel, cobalt alloys, and ceramics. Powder spray machines are usually more complex than other flame spraying equipment and are used for more sophisticated work.

Rod spray materials are usually ceramics such as aluminum oxide, chromium oxide, and zirconium. Other, more appropriate methods of applying ceramics are available and are generally more widely used because they usually provide a better coating spray.

High-Velocity Oxyfuel (HVOF) Flame Spraying. High-velocity oxyfuel (HVOF) flame spraying is quite different from other thermal spraying processes. In the HVOF flame spraying process, a mixture of oxygen and a combustible gas, such as acetylene, is fed into the barrel of a spray gun with a charge of surfacing powder. The mixture is ignited and the detonation wave accelerates the powder to

the workpiece while heating it close to or above its melting point. The cycle is repeated many times a second. The noise level is extremely high, and the process must be performed in a soundproof room.

HVOF flame spraying is most successful in applying dense, hard, carbide, and oxide coatings to critical areas of precision components. Since the base metal surface is seldom heated above 300°F (150°C), the component can be fabricated and fully heat-treated prior to coating.

Spray and Fuse (Spraywelding). *Spray and fuse (spraywelding)* is a two step thermal spray process in which a thermal spray coating is deposited and subsequently fused by heating with a torch or by placing the part in a furnace. Spray and fuse is a variation of flame spraying in which the coating material is fused after application. The spray and fuse process contains characteristics of both weld overlay and thermal spray coating and provides better corrosion resistance with less effort.

Spray and fuse coating materials are usually made of nickel or cobalt self-fluxing alloys that contain silicon or boron that are sprayed onto a part. The sprayed material is then fused to the base metal with a torch or furnace at a temperature between 1875°F (1024°C) and 2000°F (1093°C).

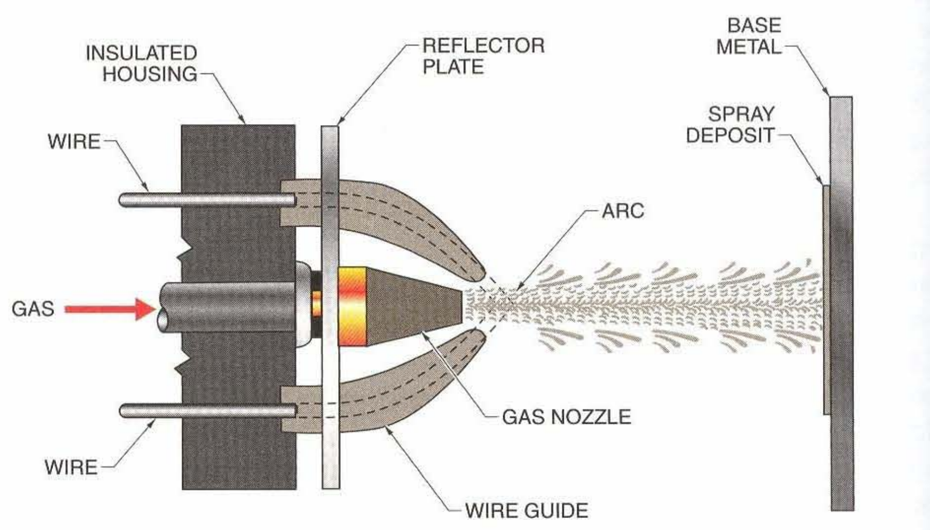
The spray and fuse process creates a smooth, nonporous, welded, hard surface that can be ground and lapped to a low RMS finish. Tungsten carbide particles are added for increased wear resistance.

The fusion process permits the fluxing additives of silicon and boron to react with oxide films on the surface and with powder particles. This allows them to wet and interdiffuse with the base metal.

Arc Spraying. Particles deposited with an arc spray unit are hotter and more fluid than those sprayed with oxyacetylene spraying equipment. The heat required to melt the wire is generated by an electric arc instead of oxyacetylene. The arc, which reaches a temperature of approximately 7000°F (3870°C), produces a stronger bond with the surface because the highly heated particles can create better fusion with lower oxide content. See Figure 24-11.

Figure 24-11. *Arc spraying equipment produces coatings with greater bond strength and lower oxide content than coatings with oxyacetylene spraying guns.*

Arc Spray Equipment
Figure 24-11



Surface Preparation and Part Design

Before surfacing, a part must be machined and excess material removed to level out a worn surface, provide for the thickness of the spray coating, and remove contaminated materials. The part is machined undersize to allow for the thickness of the coating. A lathe is commonly used on cylindrical parts to reduce part diameters.

The success of any thermal spraying process depends on having a clean surface that has been properly roughed. All traces of oil, dirt, scale, rust, and other debris must be removed. Nonporous surfaces may be cleaned using steam, vapor degreasing, hot detergent washing, or industrial solvents. Porous materials must be baked at temperatures from 400°F (204°C) to 600°F (315°C) to remove contaminants from the pores.

Roughing the surface provides mechanical anchorages for the splats. A *splat* is a flattened particle that cools rapidly and solidifies as it strikes a metal surface. Grit blasting is commonly used to rough a surface. Grit blasting abrasives may be steel grit, hard sand, aluminum oxide, or silicon carbide. The surface profile to be achieved by grit blasting varies between 1 mil and 5 mil depending on the thermal spraying method. Another method of roughing a surface is to run a knurling tool over the area to produce ragged threads, thus enabling better bonding.

Occasionally, after a surface is prepared, a thin layer of molybdenum is sprayed on to produce a fusion bond, allowing greater adherence of the subsequent spray coatings. Once the surface is properly cleaned and roughed, areas not to be coated are masked with thermal spray tape to prevent overspray. White metals, such as aluminum or magnesium, are cleaned with aluminum oxide or quartz.

Gases used for flame spraying are acetylene, methylacetylene-propadiene (MAPP), propane, and propylene. Hydrogen may be used to spray metals such as tin, zinc, and aluminum that have a low melting point.

Thermal Spray Coatings

Thermal spray coatings should be applied within four hours of surface preparation; otherwise, surface oxidation and rusting can compromise the mechanical bond between the coating and the base metal. *Mechanical bond* is the joining of two components by locking, compression, or surface tension.

Properly cleaning and roughing the part surface ensures that thermal spray coating can be successfully applied.

Surfaces are generally preheated to eliminate moisture that may interfere with bonding. Preheating to 200°F (93°C) to 250°F (121°C) removes moisture and aids bonding.

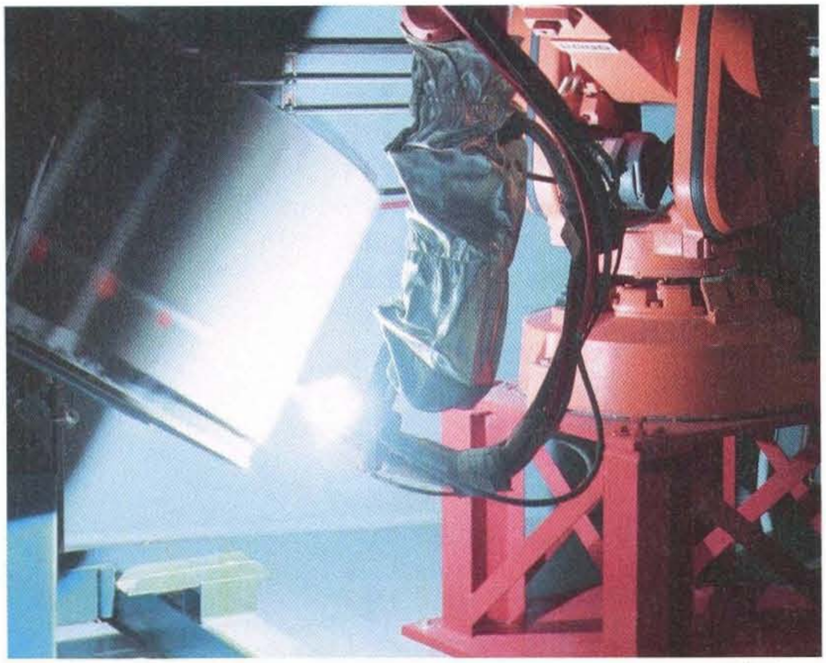
Thermal spray coatings are applied at a high velocity in the form of finely divided molten or semi-molten drops that produce a coating that adheres to a surface. The velocity range possible is determined by the design of the surfacing gun. Cohesion is achieved by intermingling of the splats and mechanical bonding of the splats and the base metal. Thermal spray consumables can be metals, ceramics, cermets, or plastics. Materials used for thermal spraying must become plastic when heated, and not degrade on heating. The type of coating used is determined by the process.

Thermal spray coatings are somewhat porous and may allow corrosives to leak through to the base metal; however, they also absorb oil and provide complete lubrication and protection from porosity. Preventing porosity is more critical in applications that are subject to acids and other corrosive materials. Adjusting the gas and air regulators and maintaining the proper distance of the surfacing gun from the workpiece helps to control porosity. However, too much effort to

When spraying flat surfaces, the surfacing gun is moved back and forth to allow a full, uniform deposit. Spraying should begin beyond one edge of the area to be covered and continue beyond the opposite end.

reduce porosity usually results in hard, brittle, and highly oxidized coatings that are likely to fail in service.

Oxidation normally occurs within the melting flame and as the metal particles fly to the surface. Generally, little oxidation takes place as the metal is melted unless the gas-fuel mixture is oxidizing. The most common causes of oxidation are overheating of the coating, excessive use of oxygen, and spraying at too great a distance from the workpiece. To protect against oxidation, metals can be aluminized or coated with a nickel-chromium deposit and then heat treated.



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When surfacing using an automated plasma sprayer, wire feed, amount of spray, gas and oxygen pressure, and other parameters are preprogrammed by the operator.

Posttreatments applied after thermal spraying include sealing to prevent corrosion and/or lengthen the service life of a part; diffusing to provide corrosion resistance; and surface finishing. Surface finishing processes include machining, grinding, buffing (polishing), and abrasive tumbling.

Thermal Spraying Operation

The wire feed speed, amount of spray, and gas and oxygen pressure must be regulated according to the recommendations established for the equipment to be used and the type of thermal spraying to be done. Air pressure is normally set for 60 psi. The use of a flowmeter ensures accurate control of the gas flow. A slight increase in air pressure provides a finer coating and, similarly, a decrease in air pressure produces a coarser coating.

The tip of the melting wire should project beyond the end of the air cap. The length of the projection depends largely on the material being used. A recommended practice is to speed up the wire feed until chunks of wire are being ejected, then reduce the wire feed until the ejection of chunks stops.

Each coating should be between .003″ and .005″ thick, or as light as possible. Too heavy a coating produces an irregular and stratified surface. The actual movement of the surfacing gun is similar to paint spraying. The nozzle should be kept approximately 4″ to 10″ away from the surface and moved with a uniform motion. If the gun is held too close to the work, minute cracks form in the coating. Too great a distance produces a soft, spongy deposit with poor physical properties. The gun travel speed is also important. When the travel speed is too rapid, the coating develops high oxide content.

After the first layer, either the workpiece or the gun is rotated 90° and the spraying pattern is repeated for each subsequent coating until the required thickness is built up. On cylindrical pieces, the work is generally fastened in a lathe with the gun mounted on a traveling carriage.

POINTS TO REMEMBER

1. With surfacing welds, the surfacing material creates a metallurgical bond with the base metal. With thermal spray coating, the bond is mechanical.
2. Erosion (low-stress abrasion) is a form of abrasive wear in which the force of an abrasive against the surface causes the removal of surface material.
3. Adhesive wear is the removal of metal from a surface by welding together and subsequent shearing of minute areas of two surfaces that slide across each other under pressure.
4. Pitting or spalling is the forming of localized cavities in metal resulting from corrosion, repetitive sliding or rolling surface stresses, or poor electroplating.
5. Weld overlay is the application of surfacing material using a welding process that creates a metallurgical bond with the base metal through melting of the surfacing metal.
6. Weld overlay may be applied using the OAW, SMAW, GTAW, GMAW, SAW, or PAW processes.
7. Use a minimum amount of heat when surfacing using SMAW.
8. When applying surfacing with SMAW, maintain a medium arc length and do not allow the electrode coating to contact the base metal.
9. When depositing surfacing welds, remove slag after each pass.
10. Consumables may be bare filler metal or wire; coated electrode; flux-cored electrode; metal powder; or metal-cermet, self-fluxing powder.
11. Properly cleaning and roughing the part surface ensures that thermal spray coating can be successfully applied.
12. When thermal spraying flat surfaces, the surfacing gun is moved back and forth to allow a full, uniform deposit. Thermal spraying should begin beyond one edge of the area to be covered and continue beyond the opposite end.

QUESTIONS FOR STUDY AND DISCUSSION

1. What is surfacing?
2. What benefits does surfacing provide when used for repair work?
3. What types of wear do parts encounter in service?
4. What is solid particle impingement?
5. What is pitting?
6. What are the two common surfacing overlay methods?
7. What is dilution?
8. What surface defects can occur on critical work if the surface is not properly prepared?
9. Why should surfacing be done in flat position?
10. How should the torch be manipulated when surfacing large objects with SMAW where a high deposition rate is required?
11. What is the most commonly used form of thermal spraying?
12. When is high-velocity oxyfuel (HVOF) flame spraying commonly used?

Cutting Operations 25

Other Welding Processes

Cutting operations are methods of rough or final preparation of shapes and edges of metals for welding. Gouging is related to cutting and refers to excavation of metal from the surface in preparation for welding. Safety considerations are an integral part of any cutting operation.

Cutting may be controlled manually or with mechanized equipment. In manual cutting, a torch is manipulated over the area to be cut. In machine cutting, the torch is guided entirely by automatic controls. The cutting process used depends largely on the kind of metal to be cut or the cost of the operation. Common cutting processes used are oxyfuel gas cutting (OFC), plasma arc cutting (PAC), and air carbon arc cutting (CAC-A).

OXYFUEL GAS CUTTING (OFC)

Oxyfuel gas cutting (OFC) is a group of cutting processes that use heat generated by an oxyfuel gas flame. The fuel gas/oxygen mixture accelerates the chemical reaction between oxygen and the base metal, removing the metal. Cutting metal using a flame is widely used in many industrial fields. The cutting is done by means of a hand cutting torch or by an automatically controlled cutting machine. See Figure 25-1.

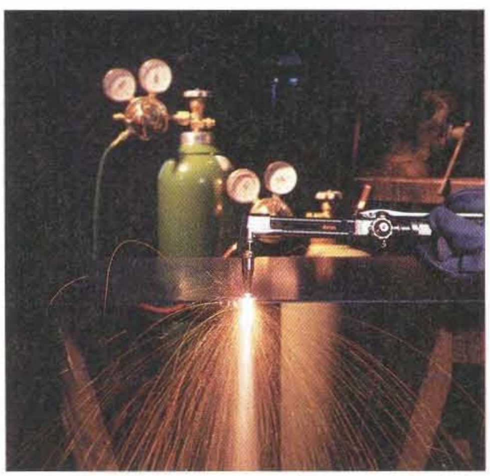

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Figure 25-1. *OFC is commonly performed with a hand cutting torch.*

The cutting of metal occurs when ferrous metals are subjected to rapid oxidation. When a piece of steel is left exposed to the atmosphere, a chemical reaction (rusting) takes place. Rust is the result of oxygen in the air uniting with the metal, causing it to oxidize. Occurring naturally, the rusting process is very slow. But if metal is heated to its ignition temperature it oxidizes and rusts much faster. The intense heat causes the mixture of oxides and metal to melt. The mixture is swept away by the flow of oxygen, resulting in a cutting action. The width of the resulting cut is called the kerf.

The oxygen used for cutting must be 99% pure. Efficiency and cutting speed are reduced with lesser oxygen purity.

Iron and low-carbon steel can be readily cut. Steels with greater carbon content must be preheated to prevent them from cracking or cooling. Cast iron is not easily cut because of its high carbon content. Stainless steels cannot be cut because chromium oxide is formed on the surface, which resists melting and shields the metal surface.

Copper and aluminum form similar high-melting-point oxides and in addition possess high thermal conductivity, making it difficult for them to be heated sufficiently.

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Oxyacetylene cutting is commonly performed on the job site since oxygen and acetylene are readily available and easy to transport.

Oxyfuel Cutting Gases

Gases mixed with oxygen and used for OFC include acetylene, natural gas, propane, methylacetylene-propadiene stabilized (MAPP), and proprietary gases. Procedures and equipment used in the OFC process do not vary much regardless of which gas is used. The heat of an oxyfuel flame brings the base metal up to melting temperature and a flow of pure oxygen is introduced to create the rapid oxidation of the steel.

Natural gas has a low-temperature, low-heat flame, making it inadequate for many welding operations. However, natural gas is commonly used for OFC because it works well for preheating and cutting materials. Propane, also called LPG or liquefied petroleum gas, may also be used for OFC and for preheating or postheating. Natural gas and propane are commonly available in many shops, making them inexpensive options for cutting operations. However, both natural gas and propane gas draw an excessive amount of oxygen during heating, which may offset their initial savings. Acetylene gas is the gas most commonly used for OFC. Because oxygen and acetylene are the most common gases used in OFC, oxyacetylene equipment and procedures are depicted.

Torches

For the rapid cutting of metal to be possible, it is necessary to use a cutting torch that will heat the iron or steel to a certain temperature and then direct the oxygen onto the heated section to perform the cutting action. See Figure 25-2.

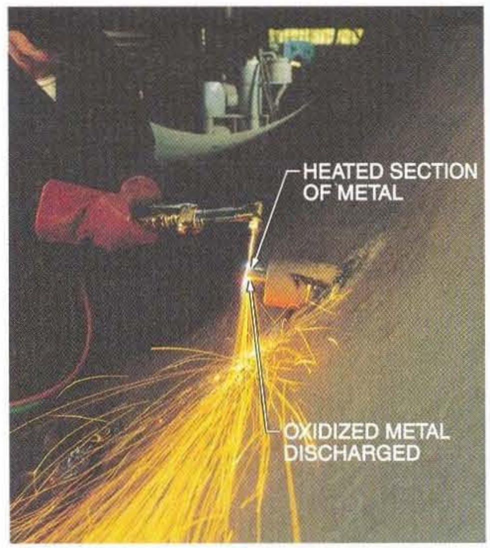

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Figure 25-2. *OFC is used to rapidly cut metal by subjecting a heated section of metal to a blast of oxygen that produces the cutting action.*

The cutting torch has conventional oxygen and acetylene needle valves. These are used to control the flow of oxygen and acetylene when heating the metal. Some cutting torches have two oxygen needle valves for fine adjustment of the neutral flame. The cutting tip is composed of an orifice in the center surrounded by several smaller orifices (preheat holes). The center orifice permits the flow of the cutting oxygen and the smaller holes are for the preheating flame. See Figure 25-3.

A cutting torch differs from a regular welding torch in that it has an additional lever to control the oxygen discharged through the center orifice.

Cutting Torch
Figure 25-3

Figure 25-3. *An oxygen cutting torch has one oxygen needle valve and one acetylene needle valve. The torch tip includes the cutting oxygen hole and several preheat holes.*

A number of different tip sizes are provided for cutting metals of varying thicknesses. In addition, special tips are made for other purposes, such as for cleaning metal; cutting rusty, scaly, or painted surfaces; rivet washing; etc. It is possible to convert a welding torch into a cutting torch by replacing the mixing head with a cutting attachment.

Oxygen and Acetylene Pressures. The correct oxygen and acetylene pressures to be used depend upon the tip size used, the type of cutting to be performed, and the thickness of the metal to be cut. See Figure 25-4. Always consult manufacturer recommendations as to the proper oxygen and acetylene pressure settings for a particular torch and tip. The given oxygen pressure cannot always be strictly followed because cutting conditions are not the same for every metal.

Piercing Holes

For steel up to ½″ thick, hold the torch over the area where the hole is to be cut until the flame has heated a small, round spot. Gradually press down the oxygen lever and at the same time raise the tip slightly. A small, round hole is quickly pierced through the metal. See Figure 25-5. For steel more than ½″ thick, move the torch slowly in a circular motion as the oxygen lever is depressed to pierce the metal.

When larger holes and circular shapes are required, trace the shapes with a soapstone. If the holes are located away from the edge of the workpiece,

The correct oxygen and acetylene pressures to be used depend upon the tip size used, the type of cutting to be performed, and the thickness of the metal to be cut.

CUTTING PRESSURE FOR METALS

Tip No.	Metal Thickness*	Oxygen Pressure†	Acetylene Pressure†
0	¼	30	3
1	⅜	30	
	½	40	
2	¾	40	
	1	50	
3	1½	45	
4	2	50	
5	3	45	4
	4	60	
6	5	50	5
	6	55	
7	8	60	6
	10	70	

* in in.
† in psi

Figure 25-4. *The correct oxygen and acetylene pressure must be used when cutting metals; correct pressures are determined by the tip size and the thickness of the metal to be cut.*

first pierce a small hole near the desired area, and then start the cut from the hole, gradually working to the drawn line and continuing around the outline. See Figure 25-6.

Piercing Holes
Figure 25-5

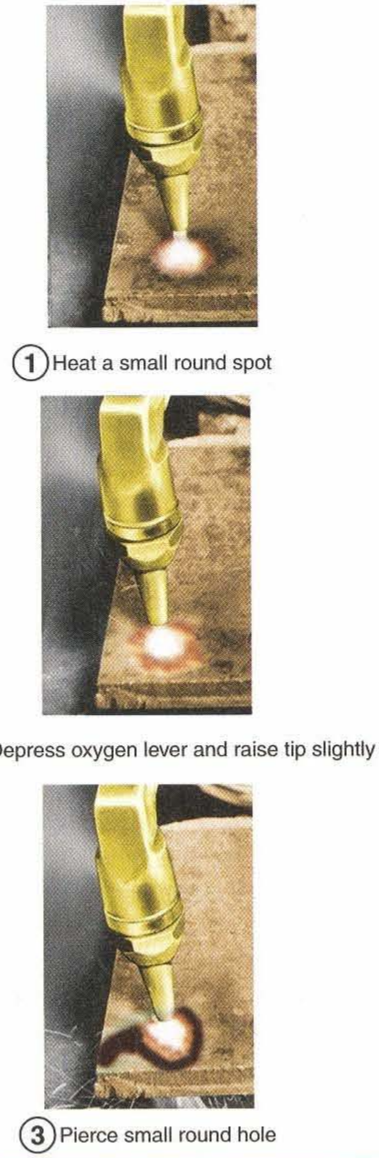


Figure 25-5. *A cutting torch can be used to pierce a hole through metal.*

Keep the preheating cones burning with a neutral flame. Hold the torch with the inner cone of the heating flame about 1⁄16" above the metal until a spot is heated to a bright red. Move the cutting torch just fast enough to make a fast but continuous cut. If the cut does not go through the metal, start the cutting process over again.

Figure 25-6. *The cutting tool must be held steady when cutting circles and large curves.*

Beveling

To make a bevel cut on steel, incline the head of the torch to the desired angle rather than holding it vertically. An even bevel may be made by resting the edge of the torch tip on the workpiece as a support, or by clamping a piece of angle iron across the workpiece. A cutting machine can also be set to automatically cut the proper beveled edge. See Figure 25-7.

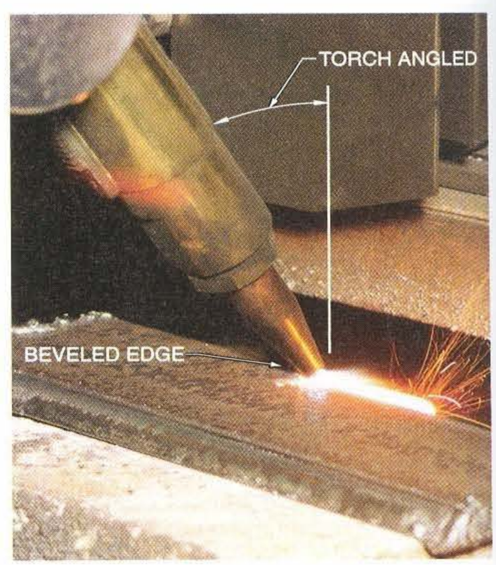


Figure 25-7. *The torch must be positioned at an angle to make a beveled edge.*

Cutting Round Stock

To cut round stock, start the cut about 90° from the top edge. Keep the torch in a vertical position (perpendicular to the cutting line) and gradually lift it to follow the circular outline of the bar. Maintain the position of the torch while ascending as well as descending on the opposite side. See Figure 25-8. Depending on the thickness of the round stock, preheat may be necessary before cutting.

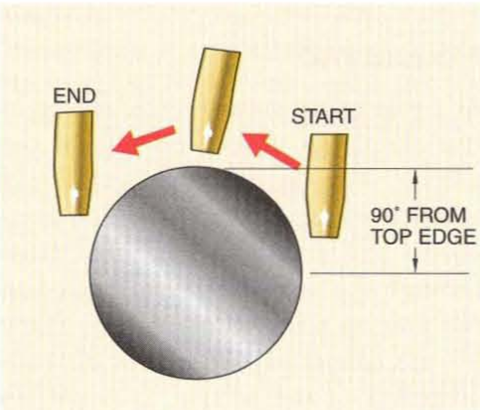


Figure 25-8. *When cutting round stock, start 90° from the top edge. Then follow around the contour of the bar.*

Cutting Cast Iron

When cutting cast iron, the chemical composition of the iron must be considered. Since cast iron has such a wide range of uses, a vast difference in quality and chemical composition can be expected. The better grades of castings are more easily cut. Do not start a cut in cast iron or heavy steel unless it can be completed without stopping.

Random grades of scrap, such as counterweights, grate bars, and floor plates, present greater difficulty in cutting and require more gas, a wider kerf, and correspondingly, a slower cutting speed. If the cut is stopped on a heavy section of cast iron or heavy steel, it is extremely difficult to start again.

The oxygen pressure and acetylene pressure needed for cutting cast iron depend upon the tip size used and the thickness of the cast iron. Always consult manufacturer recommendations for the proper oxygen and acetylene pressure settings for cutting cast iron. See Figure 25-9.

Excess heat, sparks, and slag are generated when cutting cast iron. Proper personal protective equipment is required when cutting. Welding gloves are essential, and a firebrick or suitable torch rest is desirable.

When cutting cast iron, adjust the preheating flame so it is slightly carburizing.

PLASMA ARC CUTTING (PAC)

Plasma arc cutting (PAC) is a cutting process that uses a constricted arc to remove molten metal with a high-velocity jet of ionized gas. The high-velocity jet of ionized gas issues from a constricting orifice and removes the molten metal. PAC is one of the best processes for high-speed cutting of nonferrous metals and stainless steels. It cuts carbon steel up to 10 times faster than any oxyfuel mixture, with equal quality and at less cost. See Figure 25-10.

For high-speed cutting of nonferrous metals, plasma arc cutting is the most effective.

CUTTING PRESSURE FOR CAST IRON

Tip Size	Cast Iron Thickness*	Oxygen Pressure†	Acetylene Pressure†
L-3	½	40	7 to 8
	¾	45	
	1	50	
	1½	60	
	2	70	
L-4	3	80	8 to 10
	4	90	
	6	110	
	8	120	
	10	150	
	12	170	

* in in.
† in lb

Figure 25-9. *The oxygen and acetylene pressure settings required for cutting cast iron are determined by the tip size and the thickness of the cast iron.*

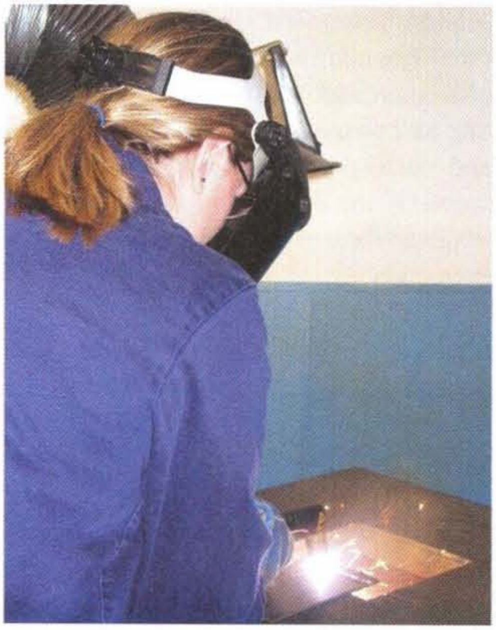


Figure 25-10. *The plasma arc cutting process is one of the best high-speed cutting processes for nonferrous metals and stainless steels.*

In plasma arc cutting, set the polarity to direct current electrode negative.

Plasma is often considered the fourth state of matter. The other three are gas, liquid, and solid. Plasma results when a gas is heated to a high temperature and changes into positive ions, neutral atoms, and negative electrons. When matter changes from one state to another, latent heat is generated. Latent heat is required to change water into steam, and similarly, the plasma torch supplies energy to a gas to change it into plasma. As plasma returns to a gaseous state, the heat is released.

When cutting aluminum and stainless steel, best results are obtained with an argon-hydrogen or nitrogen-hydrogen gas mixture. Air has proven to be the most efficient gas for use with plasma cutting; however, oxygen can also be used. Carbon steels require an oxidizing gas.

Manual PAC

In a plasma arc cutting torch, the tip of the electrode is located within the nozzle. The nozzle has a relatively small opening (orifice), which constricts the arc. The gas must flow through the arc where it is heated to the plasma temperature range. Since the gas cannot expand due to the construction of the nozzle, it is forced through the opening, and emerges at an extremely high velocity and hotter than any flame. This heat melts any known metal and its velocity blasts the molten metal through the plate creating a kerf. See Figure 25-11.

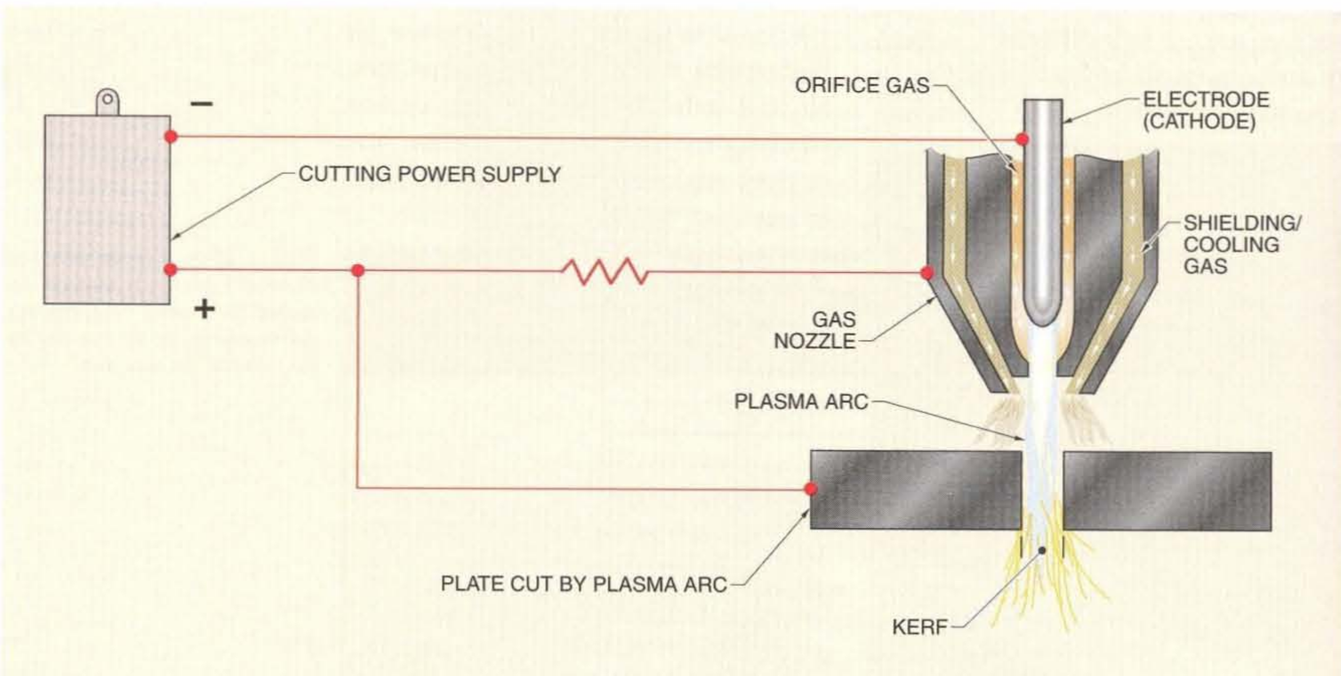


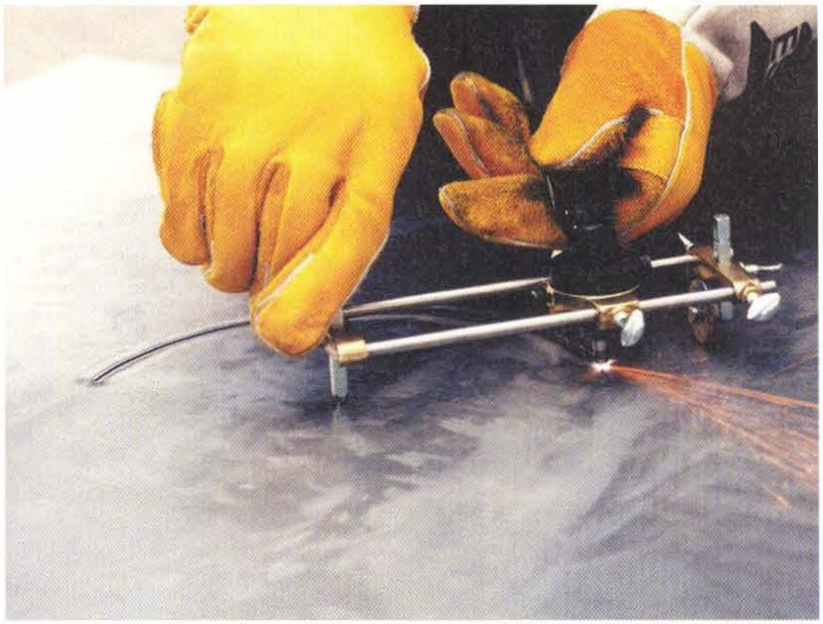
Figure 25-11. *Gases emerge from the nozzle of a plasma arc torch in the form of a high-velocity jet stream that can blast through the metal, creating a kerf.*

Because the maximum transfer of heat to work is essential in cutting, plasma arc torches use a transferred arc (the workpiece itself becomes an electrode in the electrical circuit). The workpiece is subjected to both plasma heat and arc heat. Precise control of the plasma jet can be obtained by controlling the variables—current, voltage, type of gas, gas velocity, and gas flow (cfh).

The power supply for PAC is a special rectifier-type with an open-circuit rating of 400 V. DCEN is also used. A control unit automatically controls the sequence of operations—pilot arc, gas flow, and carriage travel. A water pressure input of 60 psi to 80 psi for gas cutting and 100 psi for air cutting is necessary to keep the torch cool.

Mechanical PAC

To make a proper plasma arc cut, the power supply and the gas flow must be adjusted to the appropriate settings. See Figure 25-12. When the operator pushes the START button on the remote control panel, the control unit performs all ON-OFF and sequencing functions. The cooling water must also be turned ON or the water-flow interlock will block the starting circuit.



ESAB Welding and Cutting Products

A plasma cutting tool is commonly used for accurately cutting circles and large curves.

PLASMA ARC CUTTING CONDITIONS

Type of Metal	Thickness*	Speed†	Orifice Type	Insert‡	Power§	Gas Flow‖
Stainless steel	½	25	4 × 8	⅛	45	130 N_2
	½	70	4 × 8	⅛	60	130 N_2
	1½	25	5 × 10	5/32	85	10 H_2 175 N_2
	2½	18	8 × 16	¼	150	15 H_2 175 N_2
	4	8	8 × 16	¼	160	15 H_2
	½	25	4 × 8	⅛	50	100#
	½	200	4 × 8	⅛	55	100#
Aluminum	1½	30	5 × 10	3/32	75	100#
	2½	20	5 × 10	5/32	80	150#
	4	12	6 × 12	3/16	90	200#
	¼	200	4 × 12M**	⅛	55	250
Carbon steel	1	50	5 × 14M**	5/32	70	300
	1½	35	6 × 16M**	3/16	100	350
	2	25	6 × 16M**	3/16	100	350

* in in.
† ipm
‡ diameter
§ kW
‖ cfh
\# 65% argon, 35% hydrogen mixture
** multiport orifice

Figure 25-12. *The operator must adjust the power supply and gas flow to the appropriate settings for a particular PAC operation.*

To make a mechanized cut, the operator locates the center of the torch about 1/4″ above the surface of the workpiece to be cut and pushes the START button. Current flows from the high-frequency generator to establish the pilot arc between the workpiece and the cathode in the nozzle. Gas starts to flow, and welding current flows from the power supply. The pilot arc sets up an ionized path for the cutting arc. As soon as the cutting arc is established, the high-frequency pilot arc is shut OFF, and the carriage starts to move. See Figure 25-13.

Weld Tooling Corp.

Figure 25-13. *A semiautomatic plasma arc cutting unit is commonly used to ensure an even cut to the metal.*

When the cutting operation is completed, the arc goes out automatically because there is no ground to sustain it and the control unit stops the carriage, opens the main contactor, and shuts OFF the gas flow.

AIR CARBON ARC CUTTING (CAC-A)

Air carbon arc cutting (CAC-A) is a cutting process in which the cutting of metals is accomplished by melting with the heat of an arc between a carbon electrode and the base metal. A compressed-air line is attached directly to the torch. When the torch is in operation, the jet orifices must be positioned under the electrode. As the metal melts during cutting, a jet of compressed air is directed at the arc to blow the molten metal away from the cutting area. The jet air stream is controlled by depressing the pushbutton on the electrode holder.

Power can be supplied with either an AC or DC welding machine. However, the power requirements for a given diameter carbon electrode are higher than those for a comparable diameter SMAW electrode. Air is supplied by an ordinary compressor. In general, the required air pressure range is from 40 psi to 80 psi. See Figure 25-14.

AIR CARBON ARC CUTTING CONDITIONS

Electrode Diameter		DCEP				AC		Air Pressure	
Inches	mm	DC Electrode		AC Electrode		AC Electrode		psi	psi
		Min A	Max A	Min A	Max A	Min A	Max A		
5/32	4	90	150	–	–	–	–	40 80	280 550
3/16	4.8	150	200	150	180	150	200	40 80	280 550
1/4	6.4	200	400	200	250	200	300	40 80	280 550
5/16	7.9	250	450	–	–	–	–	80	550
3/8	9.5	350	600	300	400	300	500	80	550
1/2	12.7	600	1000	400	500	400	600	80	550
5/8	15.9	800	1200	–	–	–	–	80	550
3/4	19.1	1200	1600	–	–	–	–	80	550

Figure 25-14. *The cutting air pressure and power settings are determined by the size electrode used for air carbon arc cutting.*

Electrodes used for air carbon arc cutting are plain or copper-clad carbon-graphite electrodes. Plain carbon-graphite electrodes are less expensive, but copper-clad carbon-graphite electrodes last longer, carry higher currents, and produce more uniform cuts. Electrode holders are specially designed for air carbon arc cutting. See Figure 25-15.

Air carbon arc cutting is used to cut metal, to gouge out cracks, to remove risers and pads from castings, to remove inferior welds, and to backgouge and prepare grooves for welding. Air carbon arc cutting is used when slightly ragged edges are not objectionable. The cut area is small, and since metal is melted and removed quickly, the surrounding area does not reach high temperatures. This reduces the tendency toward distortion and cracking.

Air carbon arc cutting may be used for alumimum alloys, copper alloys, carbon steels, cast irons, nickels, alloys, and stainless steels. It is not recommended for titanium or zirconium. After air carbon arc cutting, but before welding, grinding must be used to remove the surface that has picked up carbon.

The air carbon arc cutting process must be properly performed when gouging, cutting, washing, or beveling metals to prevent carburized molten metal from remaining on the surface.

Gouging

Gouging is a cutting process that removes metal by melting or burning off a portion of the base metal to form a bevel or groove. The depth and contour of the groove are controlled by the electrode angle and travel speed. For a narrow, deep groove, a steep electrode angle and slow speed are used. A flat electrode angle and fast speed produce a wide, shallow groove. The width of the groove is also influenced by the diameter of the electrode. During all gouging operations, using the proper travel speed produces a smooth, hissing sound.

The electrode holder should be gripped so that a maximum of 6″ of electrode extends from the electrode holder to the work. For aluminum alloys the distance should be reduced to 4″. Hold the electrode holder so the electrode slopes back from the direction of travel. The jet air stream should be behind the electrode. Maintain a short arc and travel fast enough to keep up with metal removal. The arc must provide sufficient clearance so the compressed air blast can sweep beneath the electrode and remove all molten metal.

Gouging in flat position is typically performed toward the left (as the work is viewed). The electrode holder should be held perpendicular to the direction of travel, with the electrode pointing to the left. The air jet orifices should be under the electrode and should follow the electrode. See Figure 25-16.

Use plain or copper-clad carbon-graphite rods when cutting metals with the air carbon arc process.

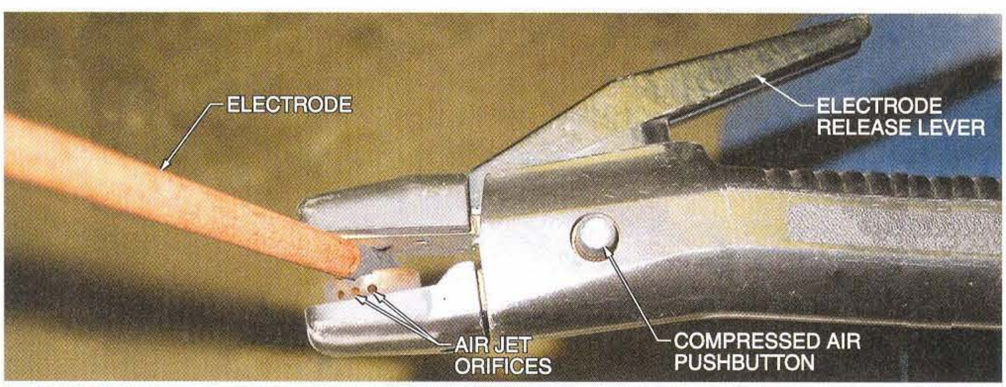
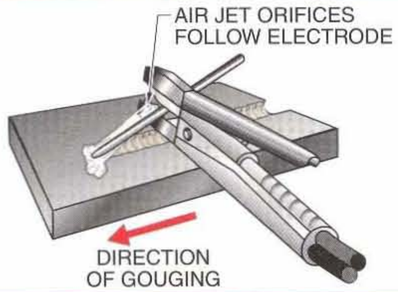


Figure 25-15. *The carbon-graphite electrode must be held in a special electrode holder designed for air carbon arc cutting.*

Figure 25-16. *When gouging in flat position, the electrode holder is held so that the electrode slopes back from the direction of travel.*

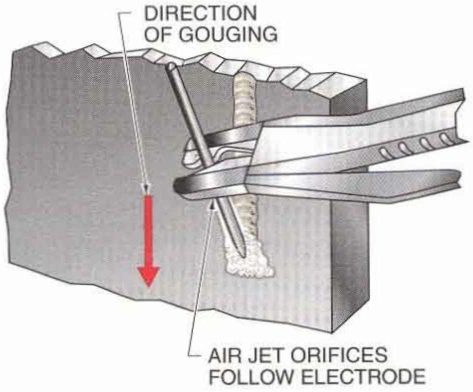
Flat-Position Gouging
Figure 25-16



For gouging in vertical position, hold the electrode holder perpendicular to the workpiece and move downward. The air jet orifices should follow the electrode so that gravity assists in removing the molten metal. See Figure 25-17.

Figure 25-17. *In vertical position gouging, the electrode holder is held perpendicular to the workpiece and the air jet orifices follow the electrode, permitting gravity to remove the molten metal.*

Vertical-Position Gouging
Figure 25-17



⚠ WARNING

To prevent accidental fire, do not perform cutting operations near combustible materials.

Gouging in horizontal position can be done by moving the electrode to either the right or the left. When traveling to the right, hold the electrode holder perpendicular to the direction of travel, with the electrode pointing toward the right, the release lever in the downward position, and the air jet orifices following the electrode. When traveling to the left, reverse the position of the electrode holder so the air jet orifices are under the electrode, the release lever is on top, and the electrode faces toward the left. See Figure 25-18.

Horizontal-Position Gouging
Figure 25-18

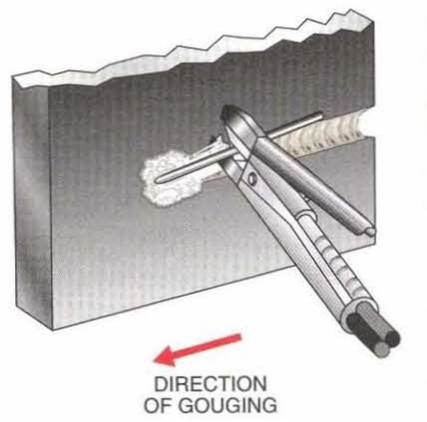


Figure 25-18. *Gouging in horizontal position can be performed from either the left or the right. The air jet orifices should always follow the electrode.*

Cutting

The cutting technique is the same as gouging except that the electrode is held at a steeper angle and is directed at a point that permits the tip of the electrode to pierce the metal being cut.

For cutting thick, nonferrous metals, hold the electrode in vertical position with a push angle of 45° and, with the air jet above it, move the arc up and down through the metal with a sawing motion.

Washing

Washing is a process of removing metal from large areas, such as removal of surfacing and of riser pads on castings. When using air carbon arc cutting for washing, weave the electrode from side to side in a forward direction to the depth desired. A push angle of 55° is recommended, with the air jet orifice following the electrode. The steadiness of the operator determines the smoothness of the surface produced. See Figure 25-19.

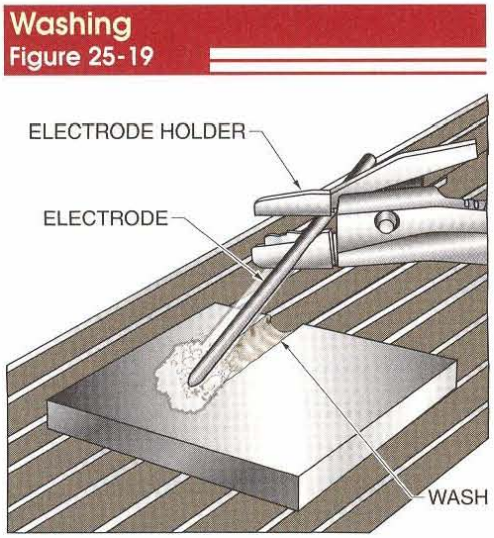


Figure 25-19. *Weave the electrode from side to side when washing with air carbon arc.*

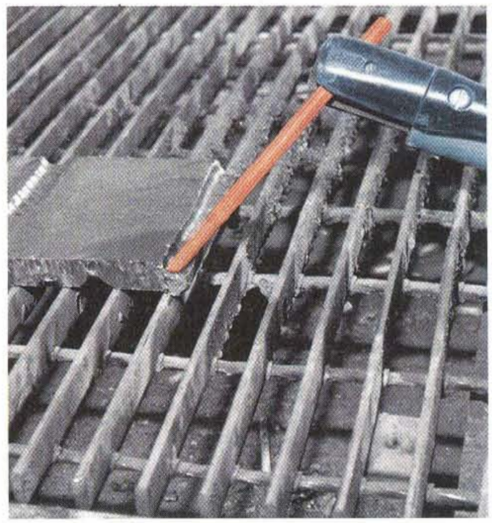


Figure 25-20. *When beveling a plate, hold the electrode at a 45° angle.*

Beveling

For beveling, hold the electrode at approximately a 45° angle, with the oxygen blast between the electrode and the metal surface. Draw the electrode smoothly along the edge being beveled. See Figure 25-20.

SAFETY PRECAUTIONS

In any cutting operation, a large amount of metal always falls to the floor. Turn pant cuffs down over the shoes to prevent molten metal from lodging inside the cuffs or shoes.

Be sure there are no combustible materials near the work area when performing cutting operations. When an excessive amount of cutting is to be done, sand should be sprinkled over a concrete floor to prevent the molten metal from heating the concrete so that it cracks and causes particles to fly upward. Another alternative is to cut over a workbench tray partially filled with sand. If the bench lacks a tray, a sand-filled pan can be placed on the floor. Eye protection must always be worn to protect against sparks and cut metal that may pop from the surface and project upwards.

Fumes are a potential health hazard. Cutting processes, such as plasma arc cutting and air carbon arc cutting, may require additional respiratory protection to protect the welder from the high volume of dust, smoke, and fumes produced by these processes. Exhaust ventilation must be available when working in enclosed or semienclosed areas. Some cutting processes generate huge amounts of noise, and in these cases, ear protection must be worn.

POINTS TO REMEMBER

1. The correct oxygen and acetylene pressures to be used depend upon the tip size used, the type of cutting to be performed, and the thickness of the metal to be cut.
2. When cutting cast iron, adjust the preheating flame so it is slightly carburizing.
3. For high-speed cutting of nonferrous metals, plasma arc cutting is the most effective.
4. In plasma arc cutting, set the polarity to direct current electrode negative.
5. Use plain or copper-clad carbon-graphite rods when cutting metals with the air carbon arc process.

Exercises

Cutting Steel Using Oxyfuel Cutting... exercise 1

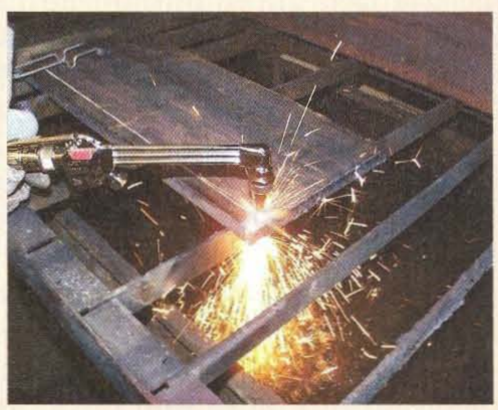
1. Obtain a piece of mild steel.
2. Use a soapstone to draw a line on the workpiece about ¾″ from one edge.
3. Position the workpiece so the line clears the edge of the welding bench.

   When an exceptionally straight cut is desired, clamp a bar across the workpiece alongside the cutting line to act as a guide for the torch.

4. Turn ON the acetylene needle valve and light the gas with a sparklighter as for welding. Turn ON the oxygen valve and adjust it for a neutral flame.

   The neutral flame is used to bring the metal to a kindling temperature. In the case of plain carbon steel, for example, the kindling temperature is between 1400°F (760°C) and 1600°F (871°C).

5. Observe the nature of the cutting flame by pressing down the oxygen control lever. When the oxygen pressure lever is depressed, additional adjustments may be needed to keep the preheating cone burning with a neutral flame.



Smith Equipment

6. Grasp the torch handle in such a way as to permit instant access to the oxygen control lever. The valve is usually operated with either the thumb or forefinger.

   Hold the torch steady to ensure making a clean, straight cut. If the tip is allowed to waver from side to side, a wide kerf is formed, which results in a rough cut, slower cutting speed, and greater oxygen consumption. To help keep the torch steady, support the elbow or forearm.

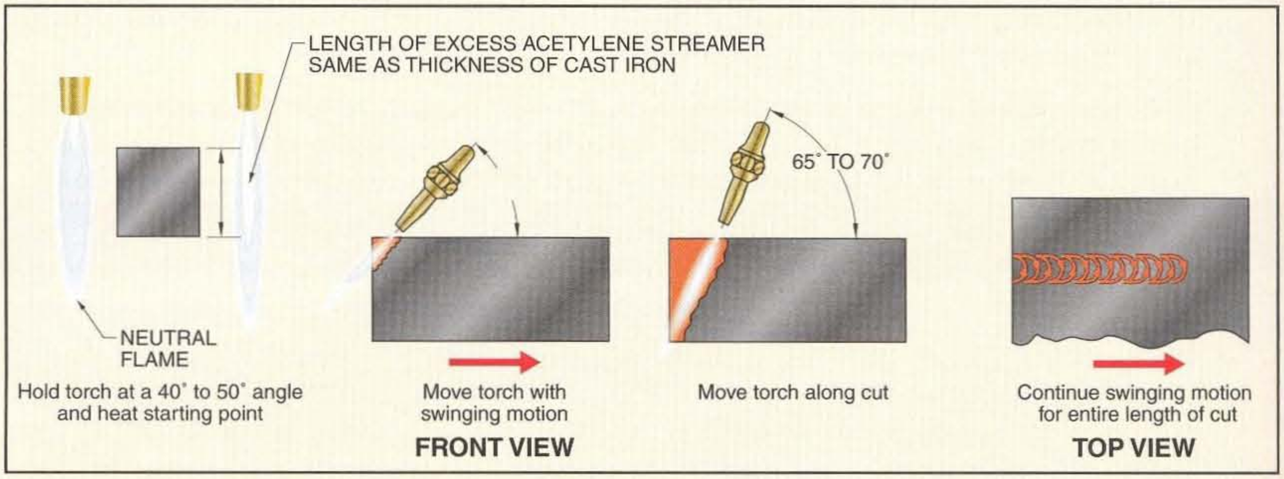
7. Start the cut at the edge of the workpiece. Hold the torch with the tip vertical to the surface of the metal and the inner cone of the heating flame approximately 1⁄16″ above the line. Hold the torch steady until a spot in the metal has been heated to a bright red.
8. Gradually press down the oxygen pressure lever and move the torch forward slowly along the line.

   The torch should be moved just rapidly enough to ensure a fast but continuous cut. A shower of sparks falling from the underside of the cut indicates that penetration is complete and the cut is proceeding correctly.
9. If the cut does not seem to penetrate the metal, close the oxygen pressure lever and reheat the metal until it is a bright red again. If the edges of the cut appear to melt and have a very ragged appearance, the metal is not burning through and the torch is being moved too slowly.
10. Initially, the workpieces may stick together, even when the cut has penetrated through. This is due to the slag produced by the cutting flowing across the workpiece. Slag is not a serious problem because it is quite brittle, and a slight blow with the hammer will separate cut sections.
11. It may occasionally be necessary to start the cut in from the edge of the plate. If so, hold the preheating flame slightly longer on the metal; then raise the cutting nozzle about ½″ and depress the oxygen lever. When a hole is cut through, lower the torch to its normal position and proceed with the cut in the usual manner.

Cutting Cast Iron Using Oxyfuel Cutting

exercise 2

1. Obtain a piece of cast iron.
2. Use a soapstone to draw a line on the workpiece about ¾″ from one edge.
3. Position the workpiece so the line clears the edge of the welding bench.



4. Light the torch and adjust the preheating flame so that it shows an excess of acetylene.
5. The excess acetylene, as indicated by the length of the white cone, must be varied to best suit the grade and thickness of the cast iron to be cut. Experience is the best guide; however, it generally varies from little or no excess of acetylene for extremely thin workpieces to an excess of a 1″ to 2″ white cone for thick workpieces.
6. Bring the tip of the torch to the starting point. Hold the torch at an angle of approximately 40° to 50° and heat a spot about ½″ in diameter to a molten condition.
7. With the end of the preheating cone about $^3/_{16}$″ from the metal, start to move the torch and open the high-pressure cutting valve. A swinging motion may be required for thick metals.

   If adjustments to the flame are needed, they should be made with the high-pressure valve wide open to avoid any change in the character of the flame during the cutting operation.
8. Gradually bring the torch along the line of the cut, continuing the swinging motion. As the cut progresses, gradually straighten the torch to an angle of 65° to 70° to ensure thorough penetration. Continue the swinging motion along the entire length of the cut.
9. On thick workpieces, ensure that there is sufficient heat to allow the cut to proceed without interruption. On thin workpieces, it is easy to lose the cut as the surface of the metal cools too rapidly and only a slight groove is made with the flame.

   Restart a cut by heating a small circle as previously described. Gradually raise the torch and incline it to cut away the lower portion of the workpiece. Proceed as before, with the exposed side of the cutting groove appearing bright. Continue to cut until finished.

QUESTIONS FOR STUDY AND DISCUSSION

1. What causes metal to rust?
2. What principle makes possible the cutting of metal by OFC?
3. How does a cutting torch differ from a welding torch?
4. What determines the oxygen and acetylene pressure that must be used for cutting?
5. What aids may be used to facilitate an even cut?
6. How can it be determined that the cut is penetrating through the metal?
7. What is the position of the torch when cutting round stock?
8. How is it possible to make a bevel cut with a cutting torch?
9. Describe the operation for piercing small holes with a cutting torch.
10. What type of flame is used for cutting cast iron, assuming a good grade of iron?
11. How is the torch held when cutting cast iron?
12. What torch motion is used for cutting cast iron?
13. What is meant by PAC?
14. What types of metals can be cut by PAC?
15. What type of electrode is used in the CAC-A process?
16. What causes the removal of molten metal when using CAC-A?
17. What does the term washing mean when using CAC-A?
18. What are some of the precautions that should be observed before engaging in any cutting operation?

Repair Welding 26

Other Welding Processes

Repair welding is a method of restoring components that have failed or have lost their ability to perform as designed. All repair options, usually mechanical repair and weld repair, must be evaluated after identifying the cause of failure. Distortion, flammability, and related safety concerns may prevent the use of repair welding. When repair welding is appropriate, a repair welding plan must be prepared that complies with relevant repair codes and safety requirements.

EVALUATING REPAIR METHODS

Repair welding is used only if it is economical or if a replacement part is not available. If a piece of equipment fails within the warranty period, the manufacturer of the equipment is contacted to determine replacement options before developing a repair plan.

Certain repairs may require the approval of authorized personnel, use of a qualified procedure, and/or preparation of supporting documentation. Repairs that are regulated by applicable codes and standards, such as repairs to aircraft, pressure vessels, and transportation containers, require documentation that repairs were made appropriately.

An understanding of how a part failed is necessary before considering repair methods. Some repair methods may not be effective on certain failures. For example, a leaking stainless steel tank that has failed by chloride stress cracking cannot be repair welded. The heat created by grinding to remove the cracks or by welding over the cracks actually accelerates the spreading of the crack, making it worse. For an effective weld repair, the leaking area must be cut out and an insert plate welded flush with the tank wall. See Figure 26-1.

Failure Analysis

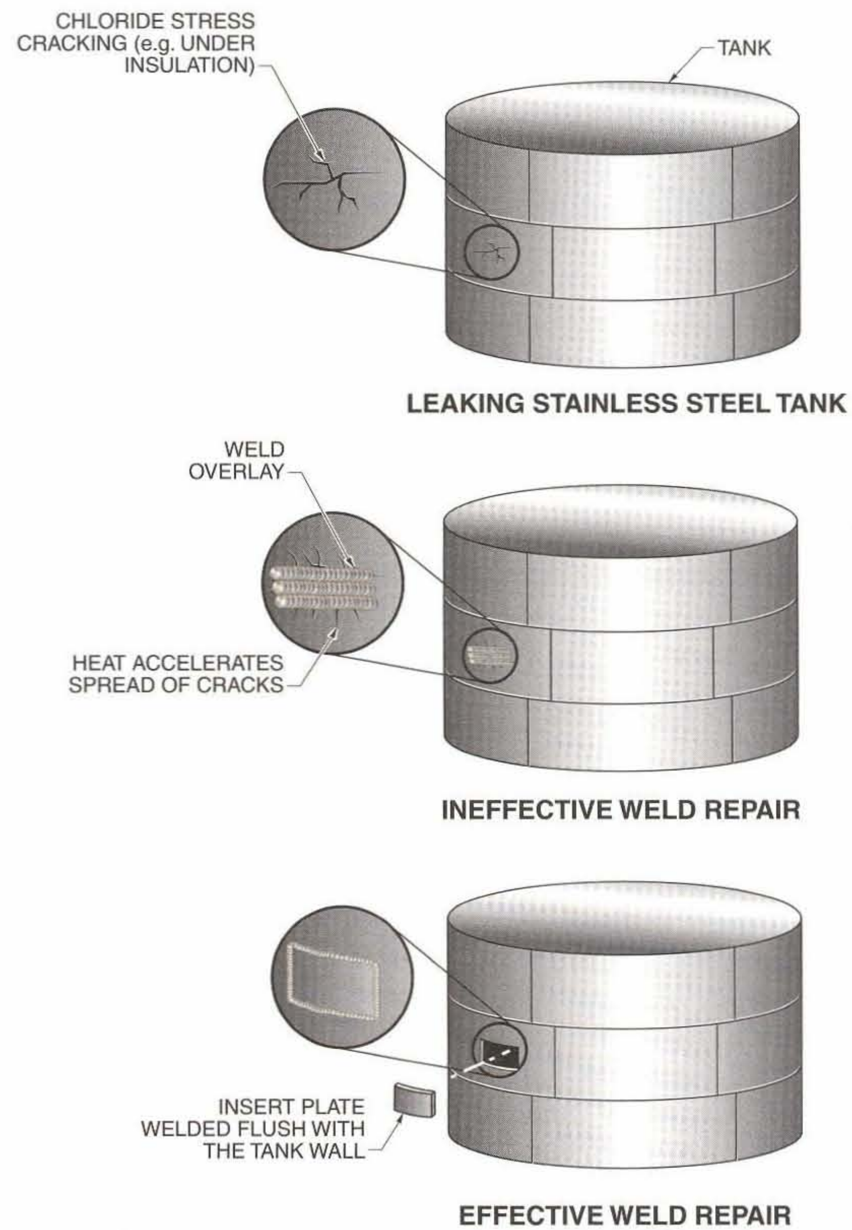
Failure analysis provides an accurate explanation of the cause of a failure or loss of performance. Failure analysis techniques consist of failure modes and effects analysis, physical failure analysis, and root cause failure analysis.

Failure modes and effects analysis is a failure analysis process that provides a diagnosis of the technical cause of failure using experience gained from previous failures. *Physical failure analysis* is a failure analysis process that provides a diagnosis of the technical cause of failure using rigorous analytical methods. *Root cause failure analysis* is a failure analysis process that determines how to prevent a failure from recurring by understanding how the actions of humans or systems may have led to the technical cause of the failure. Root cause failure analysis seeks to eliminate defects so that the failure does not recur.

An understanding of how a part failed is necessary before considering repair methods. Some repair methods may not be effective on certain failures.

Figure 26-1. *An understanding of how a part failed is necessary when selecting an effective repair method.*

Repair Weld of Stainless Steel Tank
Figure 26-1



Root cause failure analysis identifies and links the three levels of deficiency that lead to failures: technical, human, and system.

Root cause failure analysis uses failure modes and effects analysis or physical failure analysis to determine the root cause of failure. Overall, root cause failure analysis identifies and links three levels of deficiency that lead to failures:

- technical causes that lead to equipment unreliability
- human causes that lead to technical causes
- system operations causes that lead to human causes

Once the technical cause is identified, human behavior and system operations causes that contribute to the root cause of failure can be determined. Once the root cause of the failure is determined, a repair plan can be established. Mechanical repair and weld repair are two options for conducting repair welding.

An understanding of how a part failed is necessary to prevent further damage to the part. Some repair options, such as welding, may worsen the condition of the part.

MECHANICAL REPAIR METHODS

Mechanical repair is a repair weld process that consists of methods that do not create a metallurgical bond between the restored parts or at the restored surface. Mechanical repair methods produce a physical joining or resurfacing of parts without metallurgical bonding. Mechanical repair does not involve a significant heat input, which reduces the potential for distortion and residual stresses that may occur in weld repair.

Some mechanical repair methods may be performed in the field where the failure occurred; however, the failed part is generally taken to a shop for repair. Mechanical repair methods include adhesive bonding, cold mechanical repair, electroplating, thermal spray coating, and blend grinding.

Adhesive Bonding
Figure 26-2

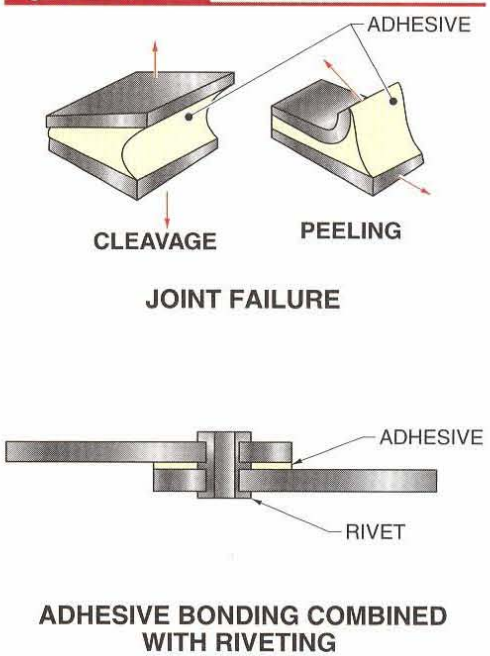


Figure 26-2. *Adhesive bonded joints may resist bonding, resulting in cleavage or peeling. However, when combined with riveting, fatigue strength is increased.*

Mechanical repair methods do not create a metallurgical bond with the surface that is being repaired.

Adhesive Bonding

Adhesive bonding is the joining of parts with an adhesive placed between the faying (mating) surfaces, which produces an adhesive bond. A satisfactory adhesive bond requires close contact between the surfaces to be joined.

Adhesive bonding is the joining of parts with an adhesive that is placed between the faying (mating) surfaces, producing an adhesive bond.

Adhesive bonded parts normally have a high resistance to shear and tension stresses because the entire surface area of the joint contributes to the strength of the bond. On the other hand, adhesive bonded parts exhibit relatively low resistance to cleavage and peeling. Thus, if the load is concentrated at the end of the bond, the joint may start to fail from the loaded end, leading to incremental separation into the body of the joint ("unzipping").

To minimize or eliminate the negative effects of peeling or cleavage, adhesive bonding may be combined with an additional mechanical fastening method such as riveting. Riveting coupled with adhesive bonding also increases the fatigue strength. See Figure 26-2.

Surface Preparation. A clean, dry surface is necessary for a quality adhesive bond. Joint failure commonly occurs because of inadequate cleaning. Surface cleanliness may be evaluated by pouring a small quantity of water over the cleaned surface. If the water breaks into individual droplets, some contamination is present. If the water uniformly covers the surface in a thin layer, the surface is clean. Surface preparation methods for adhesive bonding are abrasive cleaning, solvent cleaning, and chemical conversion.

Abrasive cleaning includes sandblasting, sanding, and wire brushing. Abrasive cleaning is used to remove heavy layers of rust or other deposits. Solvent cleaning includes hot alkaline washing, solvent wiping, and vapor degreasing. When using solvent cleaning, the solvents must be properly disposed of once cleaning is finished. Chemical conversion includes anodizing and phosphating.

Adhesive Application. Adhesives are selected based on the service requirements of the bonded part and the permitted application methods. See Figure 26-3. Epoxy phenolic adhesives form strong bonds and have good moisture retention, making them suitable for joining some metals, glass, and phenolic resins. Polyacrylate esters are not suitable for structural joints but may be used as pressure-sensitive tape.

An adhesive supplier is a good source of technical advice on adhesive selection. To make any recommendation, the adhesive supplier must be provided the following information:

- how the part is expected to perform mechanically
- thermal history of the materials being joined
- expected service temperature, including any temperature cycling

ADHESIVE APPLICATION		
Adhesive Type	**Characteristics**	**Curing Requirements**
Acrylic	• variable impact resistance • moderate strength • aluminum, copper, and steel	Room temperature up to 130°F (55°C) for 10 min to 20 min
Cyanoacrylate	• strong but brittle • jewelry, electronic components	30 sec to 5 min, room temperature
Epoxy: amine, amide, and anhydride cured	• high tensile strength, low peel strength, and moisture- and chemical-resistant • widely used for metals, ceramics, and rigid plastics	Varies from slow to fast, room temperature to 350°F (175°C)
Epoxy-phenolic	• strength retention from 300°F (150°C) to 500°F (250°C) • some metals, aluminum, steel, glass, and phenolic resins	1 hr at 350°F (175°C)
Nitrile-phenolic or neoprenephenolic	• flexible with impact resistance • metals and some plastics	Up to 12 hr, 250°F (120°C) to 300°F (150°C)
Polyamide	• good room temperature strength and toughness • aluminum and copper	Applied as hot melt and cures by cooling
Polyester	• develops strong bond • fiberglass, sometimes for metal	Min to hr, room temperature
Polyhydroxyether	• moderate strength, flexible, good adhesion • nickel and copper	Applied as hot melt and cures by cooling
Rubber-containing (e.g. neoprene, natural rubber)	• flexible • limited load bearing ability, but high impact strength and moisture resistance • most types of materials	Varies, but mostly pressure sensitive

Figure 26-3. *Various adhesives may be used depending on the service requirements of the part to be repaired.*

Manual adhesive application (using brushes, rollers, and squeeze bottles) is the simplest method of applying adhesives. Adequate ventilation is required, and personal protective equipment must be used to prevent skin contact with the adhesive.

After the adhesive is applied, the parts are brought into contact with each other and the adhesive is allowed to cure. *Curing* is a process that converts the adhesive from its applied condition to its final solid state. Curing occurs by solvent evaporation or by chemical reaction between two or more chemical components. For example, contact cements cure by solvent evaporation, whereas epoxy and urethane adhesives cure by chemical reaction.

Heat and/or pressure may be used to assist curing. The adhesive supplier should set the limits of using heat and pressure for a particular product. Excessive heat and/or pressure may result in an unacceptable bond. Excessive pressure causes adhesive to be squeezed out of the bond area, leading to a starved joint. A *starved joint* is a joint that contains insufficient adhesive to create an optimum bond.

Insufficient contact pressure leads to an excessively thick adhesive bond line, increasing the probability of a major flaw developing within the bond, which can eventually cause joint separation.

Cold Mechanical Repair

Cold mechanical repair (metal stitching) is a repair method that consists of locks and stitching pins installed into the surface of a cracked metal part. A *lock* is a precision, high-strength steel member with a multi-lobed outer contour. When installed into precision-drilled hole patterns they add strength across a crack by pulling and holding the two sides together.

Stitching pins are installed along the crack in a continuous, overlapping pattern. The special threads on the stitching pins grip the side walls of the drilled and tapped holes and draw the sides together rather than spread them apart as normal threads do.

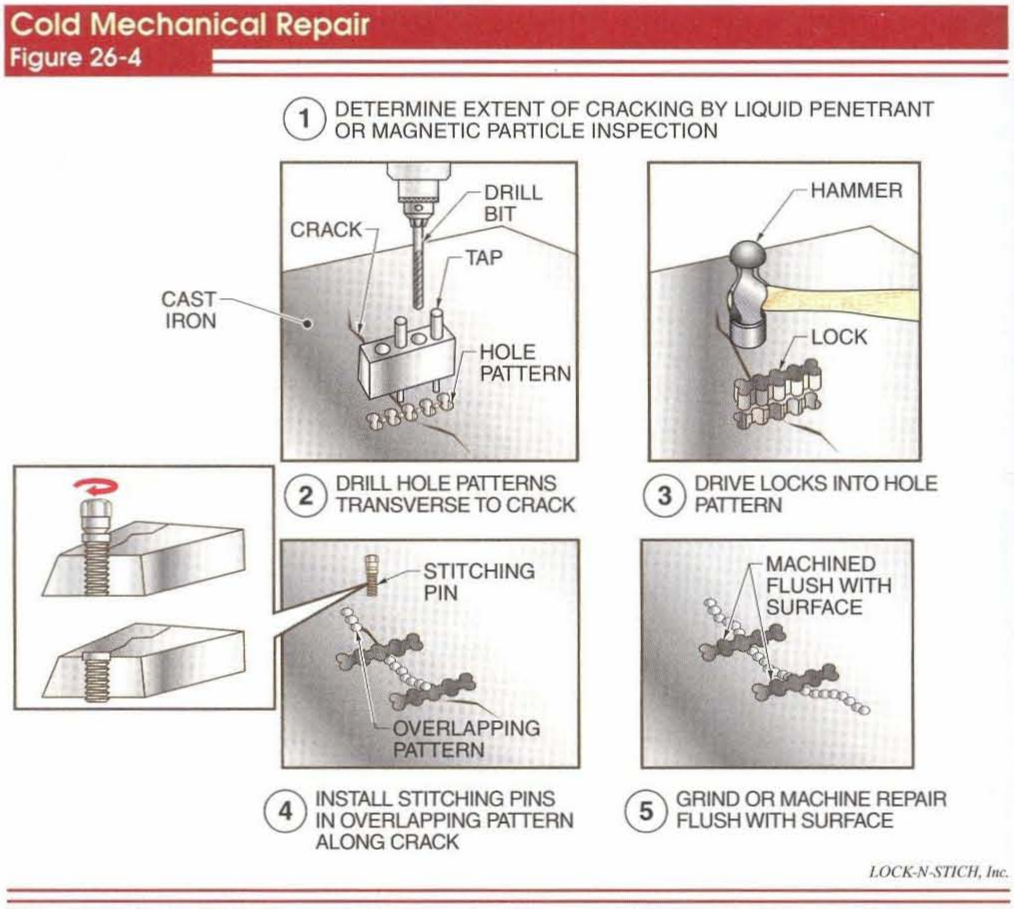
Cold mechanical repair is appropriate for repairing metals that are difficult to weld, such as cast iron. Welding on cast iron at temperatures above 1000°F often causes more problems than it solves. Cold mechanical repair prevents those problems. Cold mechanical repair can also be used on fabricated metal parts that may be difficult to replace or where welding may cause distortion.

Cold mechanical repair is commonly used on metals such as gray iron, ductile iron, aluminum, bronze, steel, and fabricated steel sections. Some applications include engine blocks and heads, pumps, compressors, machine tools, and gear boxes. Locks, stitching pins, and tooling are manufactured by companies that specialize in cold mechanical repair. Some repairs can be done with just the stitching pins or the locks. See Figure 26-4. For repairs requiring both locks and stitching pins, follow the procedure:

1. Determine the extent of cracking by liquid penetrant (PT) or magnetic particle (MT) examination.
2. Drill the hole patterns transverse to the crack along its length using the precision-drill fixtures.
3. Drive the locks into the hole pattern to lock the opposite sides of the crack together.
4. Drill, tap, and install the stitching pins in an overlapping pattern along the crack.
5. Grind or machine the repair flush with the surface.

Cold mechanical repair is a repair method that consists of locks and stitching pins installed into the surface of a cracked metal part to add strength across the crack.

Figure 26-4. *Cold mechanical repair is used on large or complex castings and forgings that are difficult to replace.*



Electroplating is the application of a thin, hard, chrome coating to repair minor damage.

Selective plating is a form of electroplating used for touch-up repairs that can be performed in the field or in the shop.

Electroplating

Electroplating is the application of a thin, hard, chrome coating to repair minor damage. The coating is typically between 5 mil and 10 mil thick. The part is masked with a nonconducting compound such as wax to screen areas not to be plated. The part is then placed in an electroplating tank that contains electroplating solution. An electric current is applied, with the part as the negative electrode in the circuit, so that metal (plating) is deposited on the part. Heavier plating thickness can be achieved by applying a copper flash plate and creating the bulk of the buildup (up to $\frac{1}{16}''$) with electroplated nickel. When electroplating is intended to produce wear resistance, a thin layer of electroplate is used.

Electroplating reduces the fatigue strength of rotating or reciprocating equipment such as shafts. Fatigue strength can be restored by peening the part before electroplating, and baking the part after electroplating. Baking should be performed for 4 hr at 350°F (175°C) or higher.

Electroplating may also be used for minor repairs by means of selective plating. *Selective plating* is a form of electroplating used for touch-up repairs on worn or damaged parts. Selective plating can be performed in the field or in the shop to repair nicks, scratches, or dings in rolls, bearing journals, wear surfaces, or oil seal surfaces. See Figure 26-5.

An anode saturated with special plating solution is used for selective plating. A rectified AC power supply is connected to the workpiece and the plating anode. Selective plating is accomplished by the relative motion of the solution-soaked anode and the workpiece. A variety of plating types is available; however, hard nickel and nickel alloy plating are most common.

SIFCO Selective Plating, Cleveland, OH

Figure 26-5. *Selective plating may be used in the field or repair shop to repair nicks, scratches, or dings on wear surfaces.*

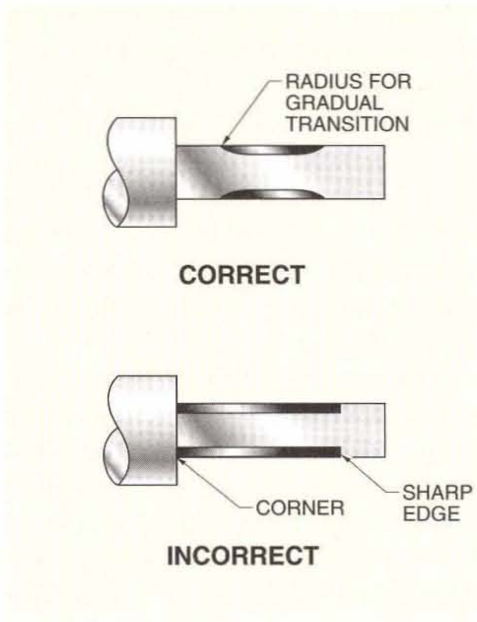


Figure 26-6. *The surfaces of parts to be repaired with thermal spray coating must be properly undercut to minimize the chance of chipping at the edges.*

Thermal Spray Coating

Common thermal spray coatings used to add wear resistance are chromium oxide and tungsten carbide. The coating material can be a rod, powder, or wire; and may be metal, ceramic, or cermet—any material that melts or becomes plastic in the heating cycle, and does not degrade when heated. Base temperatures rarely exceed 300°F (150°C) during thermal spray coating, so distortion is not usually a concern.

Thermal spray coating thicknesses range from 3 mil to 10 mil, depending on the type of coating material. Thin coatings are used for highly wear-resistant applications. Thick coatings may be used to build up badly worn base metal before application of a thin, hard, top coating. Thermal spray coatings are inherently porous and must be sealed with an epoxy coating if corrosion resistance is required.

Thermal spray coatings are susceptible to chipping and disbonding at exposed edges. The base metal should be smoothly undercut to minimize the chance of chipping at the edges of the coating. For the same reason, thermal spray coatings should not be applied to sharp corners. See Figure 26-6.

The depth of undercutting determines the finished deposit thickness. Some repairs may require undercutting as deep as 50 mil to remove scoring or other damage.

Thermal spray coatings can also be applied using the spray and fuse method. Spray and fuse coatings can be used to remove or prevent porosity. Spray and fuse coatings can be made relatively thick, from 20 mil to 80 mil, and there is some metallurgical bonding with the base metal. Abrasive particles may be incorporated into the coating to provide wear resistance. A disadvantage of the spray and fuse process is that the base metal is subjected to high temperatures, which may affect its mechanical properties.

Coating material, in the form of rod, powder, or wire, melts or becomes plastic in the heating cycle and does not degrade when heated can be used as a thermal spray coating.

Blend Grinding

Blend grinding is a mechanical repair method in which a thinned, pitted, or cracked region of a part is prepared to create a gradual transition with the unaffected surface. The smooth transition reduces stress that might lead to failure in service. Two specific conditions must be addressed before blend grinding is used: design thickness and the corrosion allowance of the structure.

Design thickness is the thickness of metal required to support the load on a part. Most parts are built with a thickness in excess of their design thickness because the product forms used to fabricate them, such as plate and pipe, are available in standard thicknesses. The designer selects the nearest available thickness above the design thickness.

Corrosion allowance is an additional thickness of metal above the design thickness that allows for metal loss from corrosion or wear without reducing the design thickness. The corrosion allowance is based on the anticipated severity of the environment in which the part is to operate. For example, a part having a ⅛″ corrosion allowance may withstand a general corrosion rate of 20 mil/yr for approximately 6 yr before repair or replacement may be necessary.

Blend grinding may be used to avoid weld repair when the remaining thickness of a structure provides adequate strength.

Blend grinding may be applied to restore the wall of a storage tank that exhibits a sharp ring of corrosion. Blend grinding eliminates the need for weld repair, provided the metal thickness in the corroded ring is above the minimum required for the service loads. See Figure 26-7.

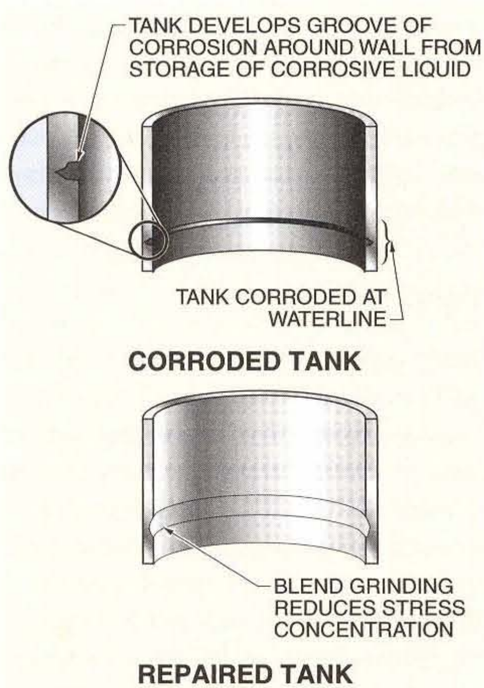


Figure 26-7. *Blend grinding can be used to repair tanks in which corrosion has developed, and is an adequate repair if the remaining tank wall has sufficient structural strength. Blend grinding helps to prevent weld repair buildup on the surface.*

Wall thickness checks are performed using ultrasonic thickness measurements to measure the extent of the area to be ground. There must be an adequate wall thickness in the tank to ensure a successful blend grinding operation.

Blend grinding is useful when weld repair is too difficult or unsafe, as in a storage tank that contains flammable vapors. Precautions must be taken to prevent sparks during grinding and to ensure that confined space entry procedures are followed. A wall thickness check is performed using ultrasonic thickness measurements to map and measure the extent of the area to be repaired, and the available wall thickness in the area.

WELD REPAIR METHODS

Weld repair is a repair weld process that consists of methods that join failed parts or restore their surface using a welding process. The heat and residual stresses created by weld repair methods must be anticipated and allowed for in the repair plan. Weld repair methods consist of structural weld repair, surfacing weld repair, wallpapering, and sleeving.

Structural Weld Repair

Structural weld repair is restoration of a load-bearing structure by welding to meet performance requirements. Examples of structural weld repairs are restoration of a broken rotating shaft, or rebuilding a storage tank wall that has worn to less than the design thickness.

Before structural weld repair is performed, confirm that the residual stresses introduced by the weld will not worsen the failure. Welding must be done in a region away from the critical high stress region where the failure occurred to prevent continued failure of the part.

When fatigue stresses are a factor, the location of the weld repair must be in a region away from a change in section thickness, where the stress concentration is highest. See Figure 26-8.

Preheating, postheating, and distortion control requirements must be detailed in the repair plan. The structural weld repair technique must minimize distortion and prevent the introduction of excessive residual stresses. If the repair is greater than ½″ thick or the joint is highly restrained, low-hydrogen electrodes should be used. A fillet weld joint is commonly a highly restrained joint and the toe should be undercut when a fillet weld joint is to be used in fatigue or high stress applications.

Controlling Fatigue Stress in Shafts
Figure 26-8

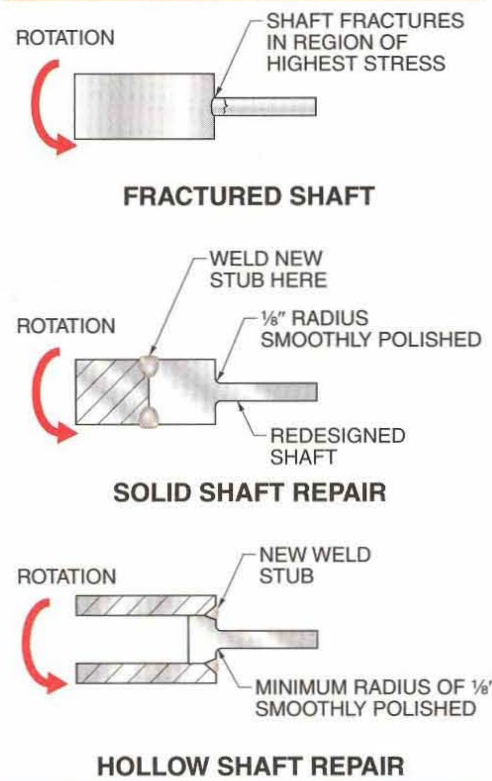


Figure 26-8. *When making a structural weld repair, ensure the weld is made away from the region of highest stress.*

Surfacing Weld Repair

Surfacing weld repair is the application of a layer, or layers, of weld metal to restore corroded, worn, or cavitated components to extend their useful life. Surfacing weld repair can be used for many applications. The compatibility of the base metal and the surfacing material determines which surfacing weld repair technique to use. As with structural weld repair, preheating, postheating, and distortion control must be detailed in the repair plan.

The compatibility of the base metal and the surfacing material determines which surfacing weld repair technique to use.

Surfacing weld repair may be done in the shop or in the field and may be performed automatically or manually. Automatic surfacing weld repair is typically performed on large corroded areas that must be rebuilt. Automatic surfacing welding machines have one or two GMAW heads and deposit metal on the vertical inside surface. The welding heads are mounted on a boom that rotates around a centerline and makes the metal deposits on the inside diameter of the corroded surface. Many automatic surfacing weld repair machines are portable enough to be used in the field as well. For manual surfacing repair in the field, SMAW is preferred, however, OFW processes can also be used because the equipment is portable.

The thickness of the surfacing weld repair should not be greater than twice the amount of wear. For hard deposits, each layer should be as thin as possible to prevent cracking, and no more than two passes should be made. A single pass is adequate if dilution between the surfacing and the component can be minimized. Surfacing weld repair should not be applied over an existing deposit that has partially worn away. A worn deposit must be completely removed by grinding.

SMAW or FCAW may be used after a worn deposit is completely ground away, and for applications in which the same component is resurfaced on a regular basis. GMAW is used with automatic or semiautomatic processes. GTAW and PAW are typically only used on small components because they are more expensive, take longer to apply, and there is less availability of wires.

OAW is used for bronze bearing surfacing weld repair. Only one pass of weld metal is required, which helps minimize distortion. However, if the repair is being done to improve corrosion resistance, the level of dilution by the base metal must be determined to ensure that one pass is adequate. If dilution of the surfacing weld could be a problem, a second pass may be required.

Peening is used to minimize distortion and crosschecking in surfacing deposits. *Crosschecking* is a series of parallel cracks about ½″ apart that occur in brittle deposits (with hardness greater than HRC 50) as they undergo stress relief. Peening is done by battering the surface with a blunt-nosed hammer while the temperature exceeds 1000°F (540°C). Peening compresses the surface and reduces residual tensile stresses. For manual repair weld processes, the welder deposits 6″ of surfacing and then peens the surface.

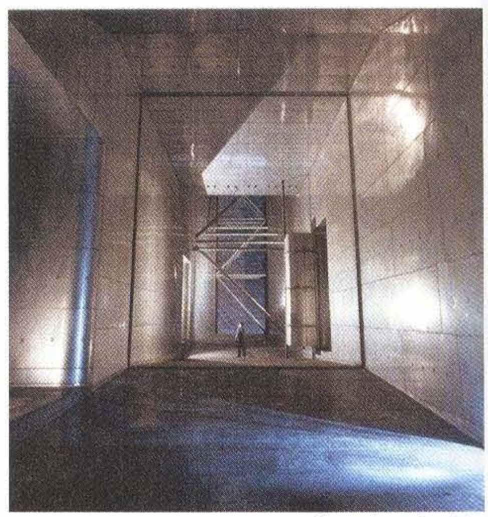
Pitting can occur from underbead cracking if surfacing weld repair is applied to heat-treatable steels without sufficient preheating and postheating. To prevent hardening of the base metal during surfacing weld repair, the base metal must be preheated to the appropriate temperature. Preheat temperature must be maintained throughout the procedure, and the component must be blanket-cooled after surfacing weld repair is completed.

Aluminum bronze surfacing welds are used to restore plungers in pumps, rams in extrusion presses, and rings on hydraulic rams. An aluminum bronze surfacing weld wears faster than the hardened steel sleeve it contacts, but can be replaced more easily. Aluminum bronzes can also be used to repair weld worn bronze bearings in heavy machinery, and to overlay cast iron gears and sheaves.

Wallpapering and sleeving are specialized repair welding processes and are less commonly used than other repair welding processes.

Wallpapering

Wallpapering is a weld repair method that uses thin, usually ¹⁄₁₆″, sheets of corrosion-resistant material that are welded to a corroded surface. The corrosion-resistant sheets are usually made of nickel alloy. GMAW is commonly used for wallpapering using short circuiting transfer or pulsed spray transfer. An intermittent fillet weld is used with adjacent sheets overlapping one another. A continuous fillet weld is made between the new sheet and the previously installed sheet. See Figure 26-9. Continuous fillet welds are required around the entire outer edge of the corrosion-resistant sheet so that no leakage occurs. If sheets larger than 1 sq ft are used, spot welds or plug welds should be made in the middle of each sheet to provide additional reinforcement.



Haynes International, Inc.

Figure 26-9. *Corrosion-resistant sheets are overlapped, with a fillet weld made between new and previously installed sheets, to repair a corroded surface.*

Sleeving

Sleeving is a weld repair method that applies surfacing to badly worn shafts by welding snug-fitting semicircular forms to cover the shaft surface. Half sleeves are usually made of a wear-resistant cobalt alloy. Transverse shrinkage tends to pull the half sleeves tightly down on the shaft when sleeves are longitudinally welded to one another. Longitudinal relief grooves are cut into the shaft to prevent heat buildup that might lead to cracking where the half sleeves are welded together.

WELD REPAIR PLANS

When developing a weld repair plan, all factors that lead to a successful repair must be considered. Factors include determining necessity of repairs, repair codes, identifying base metal, joint profile, distortion control, and repair welding procedures. See Figure 26-10.

Determining Necessity of Repairs

Before any repairs can take place, it must be determined whether a weld repair is the best course of action for the part. Some components can be repaired, while others are normally replaced. Many factors determine the type of repair to be made, or whether any repair at all should be made. Based on the effects of distortion and residual stress in the performance of the component, mechanical repair methods may offer better options. Mechanical repair methods may provide better results because if an incorrect welding procedure is used, there is an increased chance of failure.

The component or equipment name must be documented. A fabrication drawing number is assigned to the component to be designed. The fabrication drawing number for the component contains essential data, such as materials of construction and heat treatment requirements, when applicable. For shafts, the fabrication drawing number contains other essential information necessary to make an effective repair. Essential information such as shaft finish; radii, if stepped locations; special fits; existing surface treatments; and run out are included.

The technical cause of failure must be known and understood. Using an inappropriate weld repair method may cause the repair to fail rapidly. Inappropriate weld repair methods are a common problem when performing weld repair on fatigue failures.

Per AWS, D1.1, Structural Welding Code—Steel, *when performing repairs to an existing structure, all modifications must meet design requirements specified by the engineer. The engineer must prepare a comprehensive plan (weld repair plan) for all repair work to be performed.*

Repair Codes. Weld repair may be governed by a code, in which case it is necessary to follow the applicable requirements, or risk penalties for violation of the code. Some codes address repair welding requirements as a specific subject and others require welding qualifications that apply to both new and repair welding. Codes dealing specifically with repairs are sometimes called in-service inspection and repair codes. All repair codes require qualified welding procedures, qualified welders, and proof that welders are qualified to perform the required procedures. Most codes rely on ASME Section IX and AWS D1.1 to describe the requirements for qualified welding procedures and welders. Nondestructive examination must be performed by qualified examiners, and the results interpreted by inspectors qualified in the applicable code. The following specific types of equipment are covered by repair codes:

- Bridges, steel-frame buildings, and ships may only be repaired with special authorization. Structural steel and bridges are built in accordance with American Welding Society Codes. The repair work must be designed; approved. Welders must be qualified according to the code used; and the work must also be inspected. Written welding procedures are required.
- Transportation equipment and containers, such as railroad locomotives and railroad car wheels, high-strength, low-alloy steel truck frames, and compressed gas containers are not usually weld repaired. Welding is only permitted with special permission and approval.

A documented repair welding plan must be created before every job.

WELD REPAIR PLAN	
Step	**Description**
Determining Necessity of Repairs	
Part/equipment	
Fabrication drawing numbers	
Identify failure mode	
Repair options	
Repair Codes	
Name of code	
Determining Type of Repair	
Requirements for stress analysis	
Base Metal	
Base metal identification	
Effect of welding on mechanical properties	
Heat treatment requirements after repair	
Cleaning requirements before welding	
Special disassembly procedures	
Controlling Distortion	
Effect of welding on distortion	
Special alignment methods to minimize distortion	
Special repair weld sequence to reduce distortion	
Special support/bracing during weld repair	
Joint Profile	
Access of welder and filler metal to repair area	
Method of defect/crack excavation	
Method of checking for total defect/crack removal	
Final surface preparation before repair	
Welding Personnel and Equipment	
Method of qualifying welders	
Welding equipment	
Backup welders and support personnel	
Special safety requirements	
Repair Procedures	
Welding process	
Gas shielding	
Filler metal type and diameter	
Tack welds or buttering	
Number of passes (if surfacing repair)	
Welding position	
Welding technique	
Preheat/interpass temperature control	
Peening	
Postheating or cooling method	
Repair Wrap-up	
Inspection	
Testing of repair	
Final machining/surfacing treatment	
Cleanup	
Reassembly	

Figure 26-10. *A weld repair plan details all required steps to successfully complete a repair weld.*

- Aircraft may be repaired by welding, under stringent controls. The welder performing repairs on aircraft should be certified in accordance with MIL-T-5012D, *Tests; Aircraft and Missile Operators Certification.* The welder must be qualified for the type of metal being welded, the welding process to be used, and the category of parts involved.

  Furthermore, the welder should be qualified in accordance with the requirements of the Federal Aviation Administration (FAA) guidelines contained in two applicable documents: *Acceptable Methods, Techniques and Practices—Aircraft Inspection and Repair,* and the *Air Frame and Power Plant Mechanics Air Frame Handbook.* These documents provide precautionary information, techniques, practices, and methods that may be used in repair welding. Alternative techniques must be approved by the FAA. The latest version of any standard or code should always be used.

  Strict regulation of repair welding for aircraft is required because many aircraft parts are made of materials heat-treated to obtain high strength. Welding repair may compromise their mechanical properties.
- Rotating equipment such as turbines, generators, and large engines are generally covered by casualty insurance. Weld repair is performed only after approval of a written welding procedure by the insurance company.
- Fired boilers and pressure vessels are covered by various repair codes. Boilers and pressure vessels are covered by ANSI/NB-23, *National Board Inspection Code.* Additionally, pressure vessels are covered by API 510, *Pressure Vessel Inspection Code; Materials, Inspection, Rating; Repair; and Alteration.* An authorized inspector (AI) must be involved or give approval during repairs and alterations.

  The repair firm contacts the jurisdictional authority, the insurer, and the owner of the boiler or pressure vessel to ensure that the method and extent of repair is approved before making the repair.
- Storage tank repairs are covered by API 653, *Tank Inspection, Repair, Alteration, and Reconstruction,* and piping repairs by API 570, *Piping Inspection, Repair, Alteration, and Rerating.*

All welding procedures and welders must be qualified in accordance with ASME Section IX, *Welding and Brazing Qualifications.*

Some companies specialize in the repair and alteration of boilers and pressure vessels. They are authorized by the appropriate jurisdictional authority; possess a current ASME code symbol stamp covering the scope of the repair work; or have a current National Board "R" repair code symbol stamp.

Analysis of operating stresses may be required to ensure that adequate weld metal is applied.

Identifying Base Metal

The base metal to be welded must be identified, including its heat-treated and/or mechanically worked condition to determine the weldability of the metal and the proper repair performed. The integrity of the base metal is influenced by heat treatment and mechanical work.

Original documentation and drawings are helpful in determining the specifications or description of the base metal. Without documentation, the base metal can be identified by using a spark test, chemical analysis, or X-ray fluorescence analysis. A spark test can determine the approximate base metal chemistry for carbon steels.

The base metal must be identified before attempting a weld repair to determine the weldability of the metal and the type of repair that should be performed.

> **⚠ WARNING**
>
> Never perform weld repair on an unidentified base metal.

Chemical analysis requires that drillings be taken from the item and provides an accurate composition of the base metal. X-ray fluorescence analysis can identify many types of alloys.

Even when the chemical analysis or material type is known, the hardness may not be indicated. Hardness is a key indicator of mechanical properties for carbon and alloy steels. Heat treatment may be required after weld repair to restore the part to its optimum mechanical condition, particularly with machinery components, which are usually quenched and tempered to high strength levels.

Distortion Control

The effect of heat and residual stresses on tolerances and other critical dimensions must be estimated before weld repair. During weld repair, special alignment methods may be required to monitor distortion, coupled with special supports or bracing and special repair sequences to reduce distortion.

For repair of mechanical equipment, alignment markers may be used. An *alignment marker* is a center punch mark made across the joint in various locations. Alignment markers are useful in precise repair work to maintain dimensional control or alignment during welding. When repairing shafts, a dial indicator may be used to measure distortion.

Intermittent welding and back-step welding are used to reduce distortion. Intermittent welding and back-step welding help balance out stresses and the effects of heat in the repair.

> *Per AWS, D1.1,* Structural Welding Code—Steel, *the old weld is removed by grinding, machining, chipping, or gouging. Additionally before weld repair methods are performed, the surface of the structure to be repaired must be thoroughly cleaned of foreign matter, including paint to at least 2″ from the root of the weld.*

Support or bracing during weld repair is required on complex or large jobs to ensure the parts under repair do not move and are free of unnecessary forces. The supports or braces are necessary to align the parts and should not interfere while the weld repair is being made. It may be necessary to temporarily tack weld the supports or braces to the structural members to support the load.

Joint Profiles

The repair area must be accessible by the welder and the welding electrode or filler metal. Otherwise, making the repair is difficult and the chance of successfully repairing the area is low. Access to the repair area must allow the most comfortable welding position.

Root opening and backgouging requirements must be specified to achieve a full-penetration weld. If the backside of the weld cannot be backgouged, a backing bar may be required. The groove angle should be the minimum possible to reduce the amount of weld metal added, but should be sufficient to allow room to manipulate the electrode at the root of the repair.

When weld repairing casting defects, the groove angle depends on the alloy. The groove angle is opened up with cast austenitic stainless steels compared with cast steels because the former are more prone to hot cracking. Buttering the sides of the joint may be necessary with cast austenitic stainless steels to overcome susceptibility to hot cracking. Low heat input is also beneficial. Nickel alloys are even more susceptible to hot cracking than austenitic stainless steels, and the groove angle may be opened up even further.

Evaluating Defects and Cracks. Crack or defect removal is usually performed with oxyfuel gas cutting or with air carbon arc gouging. Special gouging tips should be selected based on joint preparation. For some metals,

air carbon arc gouging can introduce carbon into the surface and the HAZ. By closely watching the joint surface, it is possible to see if cracks are spreading. Metals that require preheating in welding require the same preheat conditions during cutting or gouging.

Testing for Defect and Crack Removal. Liquid penetrant examination is the most common method of checking for cracks. All liquid penetrant residues must be removed after examination by wiping with a rag soaked in a suitable solvent for solvent removable penetrant or with water for water washable penetrant.

Final surface preparation before repair is required when the surface produced by cutting or gouging is not as smooth as desired, or has been contaminated. Unless the resulting groove is smooth without undercutting or contamination, grinding or machining may be required. Grinding must achieve bright metal without excessive heat buildup. If machining is used, all fluids must be cleaned off the surface. After grinding or machining, the surface is carefully inspected for cracks and oxide particles to ensure they are removed. If magnetic particle or liquid penetrant examination is required, the surface must be cleaned one final time before testing.

Weld Repair Procedures

Weld repair procedures must take into consideration cleaning methods, disassembly, preheating, welding process, postheating, weld repair equipment, welding support personnel, safety requirements, inspecting weld repairs, and cleanup.

Cleaning Methods. Surface or subsurface contaminants can lead to cracking, porosity, or lack of fusion in a weld repair. Contaminants penetrate pits, cracks, patches, plating, and pinholes, and are difficult to remove. Metals respond in different ways to contaminants introduced from the heat of welding. Nickel alloys crack when exposed to sulfur compounds such as grease or oil. Stainless steels crack when exposed to zinc, such as from contaminated grinding wheels.

The immediate work area must be cleaned of all dirt, grease, paint, galvanizing, or any other coating. The method of cleaning depends on the material to be removed. For most construction and production equipment, steam cleaning is used. If steam cleaning is inadequate, solvent cleaning may be used, provided proper disposal conditions are established. For small components, acid or solvent dipping may be advisable. Acids must be completely removed from the base metal after dipping to prevent excessive corrosion.

Mechanical cleaning methods include grinding with discs or wheels, power wire brushing, and blast cleaning with abrasives. Blast cleaning with abrasives is very effective, but the abrasive must not be recycled or contamination can return. Blast cleaning is often the only way of removing zinc contamination because grinding and power wire brushing only smear the zinc over the surface.

After the crack is removed, grinding is required to smooth the surface. Nondestructive examination must be used to ensure cracks have been removed.

Where zinc is a specific contaminant, the dithizone test for residual zinc must be carried out. It is important to perform the dithizone test to check for cleanliness when performing repair welding on carbon steels, stainless steels, nickel alloys, or heat-resistant castings.

Disassembly. Components that are sensitive to the heat of welding must be protected or disassembled. Instrument tubing, wiring, lubrication lines, and critical surfaces must not interfere with the repair and must not be exposed to damage by heat, sparks, or weld spatter. Disassembly may require skilled mechanics experienced with the equipment. Sheet metal baffles may be used to protect adjacent machinery and fireproof cloth may be used to protect critical surfaces.

Preheating. The preheating rate depends on the amount of metal involved. For large sections of metal, the temperature rise in the component should not be greater than 100°F/hr and the entire section thickness of the area to be repaired must be at the preheat temperature for ½ hr before starting the repair. Based on the service conditions to which the component is exposed, it may be necessary to perform a bake-out. A bake-out is a temperature-control process used on a casting to remove hydrogen and other contaminants that could cause cracking during welding. A typical bake-out would be performed at 600°F (316°C) to 800°F (426°C) for 4 hr to 8 hr.

Peening is done by battering the surface with a blunt-nosed hammer, while the temperature is greater than 1000°F (540°C), to compress the surface and reduce residual tensile stresses. When manual welding, the welder deposits 6″ of weld metal and then peens the welded area.

Miller Electric Manufacturing Company

Weld repairs are commonly performed in the field. Welding equipment must be available to complete weld repairs with a minimum of downtime for the equipment.

Welding Process. The welding process is selected to achieve a sound repair consistent with the conditions at the time of repair. For these reasons, OAW and SMAW are often preferred for field weld repairs. Stringer (straight) beads are preferred over weave beads to reduce heat input. Whenever possible, the joint should be welded in the flat (1G) position to produce the most effective weld quality.

The filler metal must be selected for optimum weldability. A smaller diameter is preferred to reduce heat input, which is beneficial in reducing distortion.

Tack welds may be required to maintain alignment of the joints. Tack welds should be performed to the same qualified procedures as the main repair weld. If not, they must be ground away and the ground area inspected for cracks using liquid penetrant examination. Buttering may be used to avoid the need for preheat or postheat.

When performing a surfacing repair, the minimum number of passes necessary to meet dilution requirements is preferable.

Postheating. Postheating may be required after weld repair to restore mechanical properties. Postheating is required to stress-relieve the repair weld and reduce distortion. In some cases, slow cooling under a blanket may serve to stress-relieve the part so that a complete postheating cycle is not required. The problem with a complete postheating cycle is the possibility of further distortion.

Weld Repair Equipment. Welding equipment required for weld repairs must be readily available to prevent delays to the work. Standby equipment is also required. Equipment required for weld repair includes electrode holders, grinders, wire feeders, and welding cables. Sufficient power sources must be available to power all necessary equipment. If the job runs around

the clock, provisions for lighting and personnel comfort (such as windbreaks or covers) should be provided. Wind and rain are two conditions that adversely affect field welding. When GMAW and GTAW processes are used outside, they are restricted to fully sheltered locations since it takes very little wind to disturb them.

Welding materials must also be readily available for the entire job. Welding materials that are needed include filler metals, inserts, reinforcement, fuel for preheat and interpass temperature control, shielding gases, and fuel for engine-powered welding machines.

Welding Support Personnel. Trained welders and assistants should be capable of performing the entire job. There should be a sufficient number of welders available to perform the weld repair and, if necessary, they should be rotated to maintain quality output. For code repairs, the welder must be formally qualified to the applicable welding procedures. For noncode work, welders should be qualified to a mock-up. A *mock-up* is a simulation of the repair area on which the welder performs work in the expected position of the repair.

Safety Requirements. Special safety requirements must be met when performing weld repair. Safety requirements include confined space entry procedures, proper grounding, and correctly sized welding cables.

Confined spaces can contain life-threatening atmospheres such as oxygen deficiency, combustible gases, and/or toxic gases, and can cause entrapment. Oxygen deficiency is caused by the displacement of oxygen as welding takes place, the combustion or oxidation process, oxygen being absorbed by the vessel by corrosion, and/or oxygen being consumed by bacterial action. Oxygen-deficient air can result in injury or death. See Figure 26-11.

POTENTIAL EFFECTS OF OXYGEN-DEFICIENT ATMOSPHERES*

Oxygen Content†	Effects and Symptoms‡
19.5	Minimum permissible oxygen level
15–19.5	Decreased ability to work strenuously. May impair condition and induce early symptoms in persons with coronary, pulmonary, or circulatory problems
12–14	Respiration exertion and pulse increases. Impaired coordination, perception, and judgment
10–11	Respiration further increases in rate and depth, poor judgment, lips turn blue
8–9	Mental failure, fainting, unconsciousness, ashen face, blue lips, nausea, and vomiting
6–7	8 min, 100% fatal; 6 min, 50% fatal; 4 min–5 min, recovery with treatment
4–5	Coma in 40 sec, convulsions, respiration ceases, death

* values are approximate and vary with state of health and physical activities
† % by volume
‡ at atmospheric pressure

Figure 26-11. *Oxygen-deficient atmospheres in confined spaces can cause life-threatening conditions.*

Before entering a permit-required confined space, an entry permit must be posted at the entrance or otherwise made available to entrants. The permit must be signed by the entry supervisor. A signed entry permit verifies that pre-entry preparations have been completed and that the space is safe to enter. See Figure 26-12.

The workpiece connection must be connected to the workpiece with good electrical contact. The workpiece lead should make a firm, positive connection with the welding power source. The placement of the workpiece connection determines arc characteristics and prevents or minimizes arc blow.

Welding cables must be sized correctly for the job. A hot cable indicates the cable is too small, or the connections are inadequate. In all cases, welding cables must not be used if the insulation becomes damaged or the connections become hot.

Many repairs of in-place storage tanks are performed by companies specializing in such repairs. Repair methods must be approved by the authority having jurisdiction and the insurer of the storage tank. When repairs are made to a pressure vessel, a Form R-1, Report of Welded Repair or Alteration must be signed by the inspector who authorized the repairs and by the contractor performing the repairs. Copies must be sent to the proper state authorities, and must be retained by the vessel owner and the authorized inspector.

During welding, the quality of the repair should be continually checked to prevent problems during the formal inspection at the completion of the job.

Inspecting Weld Repairs. Inspection should be done informally during the repair and formally at the end of the repair. During welding, the quality of the repair should be continually checked to catch and correct problems before the formal inspection. The final welds should be smooth and without notches, and reinforcing, if used, should blend smoothly into the existing structure. Grinding may be necessary to maintain smooth contours and to perform surface repairs on seals. A formal inspection brief should be prepared with the types of nondestructive examinations required. Examiners must be qualified if required by specific codes; the acceptance criteria of the governing code must be used.

Testing of a repair weld may involve a pressure test such as a hydrostatic test. A pressure test is not mandatory unless specifically required by the applicable code. Other procedures may be substituted if approved by the authorized inspector or code. Examples of alternate tests include 100% radiography of repair welds; liquid penetrant examination or magnetic particle examination of all welds not radiographed; or a sensitive leak test such as a vacuum box test.

Cleanup. Cleanup includes removal of strongbacks or other clamps, and smooth grinding of the locations where such items were attached. The ground area should be inspected with liquid penetrant examination or magnetic particle examination to ensure it contains no cracks or other defects. Ground areas that require weld repairs must follow exactly the same weld procedure as the repair itself, including preheat and interpass temperature control if necessary. All weld stubs, weld spatter, slag, and other residues must be removed. Grinding dust must be removed since it is abrasive and may infiltrate working joints and bearings, creating future problems.

Reassembly is required for pieces of machinery taken apart for repair welding. Particular attention must be paid to proper fit-up. If necessary, remachining or grinding may be necessary to restore proper fit-up or alignment. All other items such as lubrication lines, cable, and conduit should be reassembled. Once all wrap-up procedures have been completed, the repaired machinery should be given an operational test before being returned to service.

Confined Space Entry Permit
Figure 26-12

✓ Confined Space   ✓ Hazardous Area   Permit No. 4672 555 11

ALL COPIES OF PERMIT WILL BE POSTED AT JOB SITE UNTIL JOB IS COMPLETED. PERMIT GOOD ONLY ON DATE(S) INDICATED.

SITE LOCATION and DESCRIPTION
Bunker Water Tank #2

PURPOSE OF ENTRY
Repair Crack in Tank

SUPERVISOR(S) in charge of crew(s). (Type of Crew-Phone #)
Michael Green Maintenance Shift II - x5924

AUTHORIZED DURATION OF PERMIT
DATE: 10/2 to 10/4
TIME: 7:00 AM to 3:00 PM

PERMIT SPACE HAZARDS (indicate specific hazards with initials)

____	**Oxygen deficiency**	(less than 19.5%)
____	**Oxygen enrichment**	(greater than 23.5%)
____	**Flammable gases or vapors**	(greater than 10% of LEL)
____	**Airborne combustible dust**	(meets or exceeds LEL)
____	**Toxic gases or vapors**	(greater than PEL)
____	**Mechanical Hazards**	
____	**Electrical Shock**	
____	**Materials harmful to skin**	
____	**Engulfment**	
____	**Other:**	

*** BOLD DENOTES MINIMUM REQUIREMENTS TO BE COMPLETED AND REVIEWED PRIOR TO ENTRY***

REQUIREMENTS COMPLETED	DATE	TIME	REQUIREMENTS COMPLETED	DATE	TIME
Lock Out/De-energize/Tag-out	10/2	09:00	**Full Body Harness w/"D" ring**	10/4	08:00
Line(s) Broken-Capped-Blanked	10/2	11:00	**Emergency Escape Retrieval Equip**	10/4	08:00
Purge-Flush and Vent	10/3	09:00	**Lifelines**	10/4	08:00
Ventilation	10/3	10:00	**Fire Extinguishers**	10/4	08:00
Secure Area (Post and Flag)	10/2	08:00	**Lighting (Explosiveproof)**	10/4	08:00
Breathing Apparatus	10/4	08:00	**Protective Clothing**	10/4	08:00
Resuscitator-Inhalator	10/4	08:00	**Respirator(s) (Air Purifying)**	10/4	08:00
Standby Safety Personnel	10/4	08:00	**Burning and Welding Permit**	10/4	08:00

Note: Items that do not apply enter N/A in the blank.

** RECORD CONTINUOUS MONITORING RESULTS EVERY 2 HOURS

CONTINUOUS MONITORING** TEST(S) TO BE TAKEN	Permissible Entry Level		10/4							
PERCENT OF OXYGEN	**19.5% to 23.5%**		20.5	20.6	20.7	20.5	20.5			
LOWER FLAMMABLE LIMIT	**Under 10%**		5	5	5	5	6			
CARBON MONOXIDE	**35 PPM+**		0	0	0	0	0			
Aromatic Hydrocarbon	1 PPM+	5 PPM*	2	1	2	1	1			
Hydrogen Cyanide	(Skin)	4 PPM*	N/A							
Hydrogen Sulfide	10 PPM+	15 PPM*	N/A							
Sulfur Dioxide	2 PPM+	5 PPM*	3	2	2	2	2			
Ammonia		35 PPM*	N/A							

* Short-term exposure limit: Employee can work in area up to 15 min.
\+ 8 hr time weighted avg: Employee can work in area 8 hr (longer with appropriate respiratory protection).

REMARKS:

GAS TESTER NAME & CHECK #	INSTRUMENT(S) USED	MODEL &/OR TYPE	SERIAL &/OR UNIT #
Marty James	Combination Gas Meter	Industrial Scientific	15A

SAFETY STANDBY PERSON IS REQUIRED FOR ALL CONFINED SPACE WORK

SAFETY STANDBY PERSON(S)	CHECK #	NAME OF SAFETY STANDBY PERSON(S)	CHECK #
Kate Washington	3312		
Tony Linder	3318		

SUPERVISOR AUTHORIZING ENTRY
ALL ABOVE CONDITIONS SATISFIED Michael Green

AMBULANCE 2800   FIRE 2900
Safety 4901   Gas Coordinator 4529/5387

Figure 26-12. *A confined space entry permit form documents preparations, procedures, and required equipment.*

POINTS TO REMEMBER

1. An understanding of how a part failed is necessary before considering repair methods. Some repair methods may not be effective on certain failures.
2. Root cause failure analysis identifies and links the three levels of deficiency that lead to failures: technical, human, and system.
3. Mechanical repair methods do not create a metallurgical bond with the surface that is being repaired.
4. Adhesive bonding is the joining of parts with an adhesive that is placed between the faying (mating) surfaces, producing an adhesive bond.
5. Cold mechanical repair is a repair method that consists of locks and stitching pins installed into the surface of a cracked metal part to add strength across the crack.
6. Electroplating is the application of a thin, hard, chrome coating to repair minor damage.
7. Selective plating is a form of electroplating used for touch-up repairs that can be performed in the field or in the shop.
8. Coating material, in the form of rod, powder, or wire, melts or becomes plastic in the heating cycle and does not degrade when heated can be used as a thermal spray coating.
9. Blend grinding may be used to avoid weld repair when the remaining thickness of a structure provides adequate strength.
10. The compatibility of the base metal and the surfacing material determines which surfacing weld repair technique to use.
11. Wallpapering and sleeving are specialized repair welding processes and are less commonly used than other repair welding processes.
12. A documented repair welding plan must be created before every job.
13. The base metal must be identified before attempting a weld repair to determine the weldability of the metal and the type of repair that should be performed.
14. After the crack is removed, grinding is required to smooth the surface. Nondestructive examination must be used to ensure cracks have been removed.
15. During welding, the quality of the repair should be continually checked to prevent problems during the formal inspection at the completion of the job.

QUESTIONS FOR STUDY AND DISCUSSION

1. What are the three levels of deficiency analyzed by root cause failure analysis?
2. When are mechanical repairs required rather than repair welding?
3. What is adhesive bonding?
4. Why must an adhesive bonded joint be allowed to cure?
5. On what type of metal is cold mechanical repair primarily used?
6. What is electroplating?
7. What type of bond is produced between thermal spray coating and the base metal?
8. Why must thermal spray coatings be applied to smooth base metals and not sharp corners?
9. What conditions must be present in order to use blend grinding as a repair option?
10. What are the two major types of weld repair?
11. What is the benefit of peening a surface?
12. What welding process is commonly used for wallpapering?
13. Why is it important to know the type of base metal before attempting a weld repair?
14. Why is cleaning of the surface so important to repair welding?
15. What common types of inspection are used to inspect weld repairs?

Pipe Welding 27

Other Welding Processes

Pipe is used to transport oil, gas, and water in a system. Pipe is also used to transport chemicals (nitrogen, air) or utilities. Pipe is used extensively for piping systems in buildings, refineries, and industrial plants. The use of pipe has gained acceptance in construction and often takes the place of beams, channels, or angle iron. Pipe is commercially available in a wide range of diameters, wall thicknesses, and lengths.

Welding is the easiest, most common method of joining sections of pipe. Pipe welding eliminates complicated threaded joint designs, permits free flow of liquids, and reduces installation costs. Welding is also a practical and effective cost-cutting technique in joining noncritical low-pressure piping for refrigeration or HVAC systems. Welded joints are not designed to be disassembled. Repair or replacement requires removal of a section by cutting.

PIPE CLASSIFICATION

Pipe for most applications is made from stainless steel or low-carbon steel. Special applications may use chrome-moly steel, nickel steel, wrought steel, low-alloy steel, copper, aluminum, or brass piping. Pipe is selected based on the working load pressure and the material to be controlled in the pipe. For example, steam lines in a nuclear power plant must be strong enough to withstand high pressures without the possibility of failure caused by defective welds or corrosion.

Pipe dimension is determined using the nominal pipe size (NPS). For pipe 14″ and larger in diameter, the NPS is the same as the outside diameter. Pipe wall thickness is specified using one of two standards: ANSI or ASTM/ASME. ANSI classifies pipe thicknesses using schedule numbers (Schedule 40, 60, 80, etc.). ASTM and ASME classify pipe thickness using nominal inside diameter as required by load requirements. The nominal inside diameter is determined using standard weight pipe. The three standard pipe weights are standard (STD), extra-strong (XS), and double extra-strong (XXS). As the wall thickness of extra-strong pipe and double extra-strong pipe is increased, the inside diameter is reduced. The outside diameter remains constant in pipe classifications. See Appendix.

For example, pipe with an NPS of 3″ has an outside diameter of 3.5″. Standard pipe has an inside diameter of 3.068″. Extra-strong pipe has an inside diameter of 2.9″. Double extra-strong pipe has an inside diameter of 2.3″. See Figure 27-1.

Pipe can be classified as thin-wall or thick-wall. Thin-wall pipe has a wall thickness from 1/8″ to 5/16″. Thick-wall pipe has a wall thickness greater than 5/16″.

⚠ CAUTION

Determine certification requirements for welders before proceeding with any pipe welding application.

PIPE DIAMETERS							
NOMINAL PIPE SIZE*	OUTSIDE DIAMETER†	INSIDE DIAMETER*			NOMINAL WALL THICKNESS*		
		STANDARD	EXTRA-STRONG	DOUBLE EXTRA-STRONG	SCHEDULE 40	SCHEDULE 60	SCHEDULE 80
⅛	.405	.269	.215		.068	.095	
¼	.540	.364	.312		.088	.119	
⅜	.675	.493	.423		.091	.126	
½	.840	.622	.546	.252	.109	.147	.294
¾	1.050	.824	.742	.434	.113	.154	.308
1	1.315	1.049	.957	.599	.133	.179	.358
1¼	1.660	1.380	1.278	.896	.140	.191	.382
1½	1.900	1.610	1.500	1.100	.145	.200	.400
2	2.375	2.067	1.939	1.503	.154	.218	.436
2½	2.875	2.469	2.323	1.771	.203	.276	.552
3	3.500	3.068	2.900	2.300	.216	.300	.600
3½	4.000	3.548	3.364	2.728	.226	.318	
4	4.500	4.026	3.826	3.152	.237	.337	.674
5	5.563	5.047	4.813	4.063	.258	.375	.750
6	6.625	6.065	5.761	4.897	.280	.432	.864
8	8.625	7.981	7.625	6.875	.322	.500	.875
10	10.750	10.020	9.750	8.750	.365	.500	
12	12.750	12.000	11.750	10.750	.406	.500	

* in in.
† bw gauge

Figure 27-1. *The inside diameter of pipe changes as the wall thickness increases.*

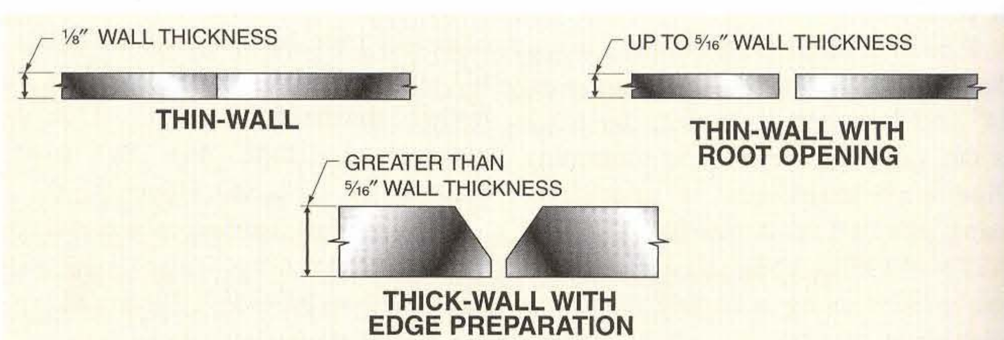
Small-diameter pipe with a wall thickness of less than ⅛″ is not typically beveled.

The wall thickness of the pipe to be welded determines the joint preparation required. Thin-wall pipe with a wall thickness of ⅛″ or less does not commonly require edge preparation or beveling. Pipe with a wall thickness greater than ⅛″ usually requires edge preparation. See Figure 27-2.

PIPE CONNECTIONS

Welding is the most common method of joining large-diameter pipe. Welded pipe connections cause less restriction to the flow of materials in the pipe. When properly welded, there is no gap between pipe sections and joint strength is consistent with

Figure 27-2. *Thick-wall pipe has a wall thickness greater than 5⁄16″. Wall thicknesses over ⅛″ require some edge preparation.*



the surrounding sections of pipe. Welded joints may be made with butt-welded fittings or socket fittings. See Figure 27-3.

Butt-welded fittings require edge preparation of the pipe with a maximum 3/16″ root opening. The groove angle should be between 70° and 80°. A backing ring is recommended for butt-welded pipe with a wall thickness over 3/4″. Socket fittings join pipe and fittings using sleeves that are welded, brazed, or soldered. A socket fitting does not require edge preparation. Socket fittings are used on pipe with less than 2″ outside diameter (OD).

PIPE JOINT PREPARATION

Pipe joints must be properly prepared before welding. Common joint preparations used with pipe include the single-V-groove and single-U-groove. The groove angle, root face, and root opening vary based on pipe diameter. Pipe weld specifications commonly used on 5/16″ thick-wall pipe call for a 75° groove angle (37.5° bevel angle). The root opening is approximately 3/32″ to 1/8″. The root face is approximately 3/32″ to 1/8″. The root opening and groove angle increase as required for pipe with greater wall thicknesses. See Figure 27-4.

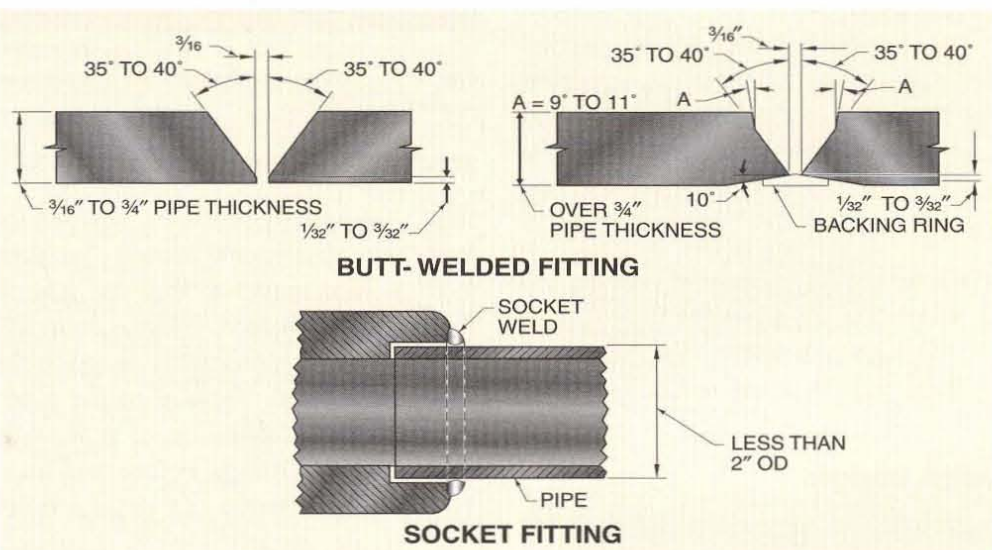


Figure 27-3. *Welded joints may be made with butt-welded fittings or socket fittings.*

Pipe Joint Preparation
Figure 27-4

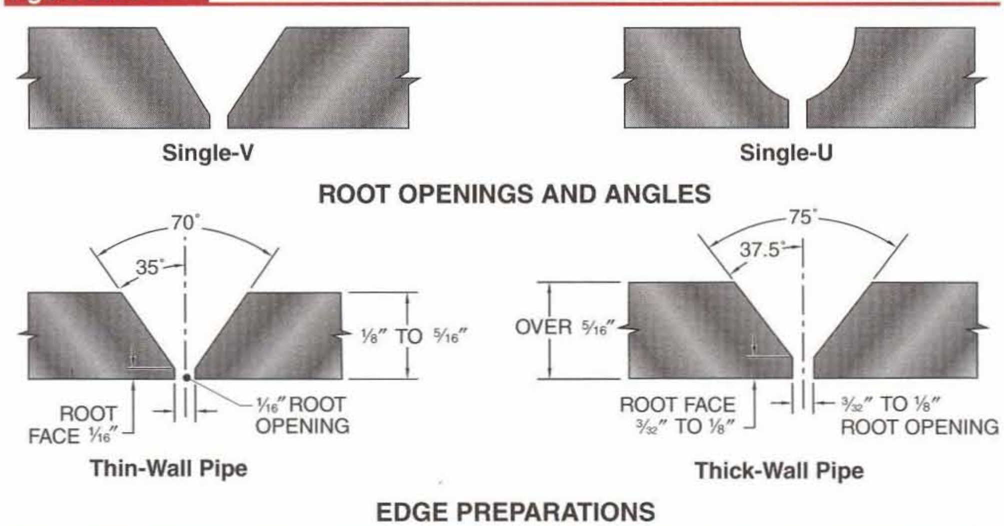


Figure 27-4. *Root openings, angles, and joint preparations vary for both thin-wall and thick-wall pipe.*

In addition, various joint preparations may be required to ensure proper penetration during welding. The groove face can be altered to allow access and to limit the amount of filler metal required without compromising weld strength. Joint preparation is determined by pipe wall thickness, pipe composition, and the welding process used.

Small-diameter pipes with wall thicknesses less than ⅛″ are commonly welded without any joint preparation. The ends are simply butted together with a small separation to ensure complete fusion. Most pipe with wall thicknesses over ⅛″ require some joint preparation.

Pipe welding techniques are affected by pipe dimensions, location, requirements of the pipe and the weld, and welding equipment available. The following steps are used to prepare pipe for welding:

1. Select proper joint design for the job.
2. Clean the joint surface.
3. Align and fit-up the pipe joints.
4. Tack weld the pipe sections together.

⚠ WARNING

Improper fit-up in piping can lead to catastrophic failure of a pipe, especially in high-pressure piping.

Joint Design

Joint design specifications vary depending on the size and composition of the pipe and the thickness of the pipe wall. However, a single-V groove is used for most thick-wall pipe welding. The joint edges must be smooth and free of defects and contaminants. Edges should be worked with a wire brush, if necessary, to remove defects or discontinuities and contaminants.

Pipe typically arrives from the supplier already prepared and beveled to standard specifications. A bevel can be cut or ground in the field; however, this method is time-consuming and is less accurate than machine-beveling.

Whether performed at the supplier's or at the shop, beveling of the joint is usually done with an oxyacetylene beveling machine or pipe machine. A cutting torch can be used to bevel the edges if joint preparation must take place at a job site where a beveling machine is not available. See Figure 27-5.

Thermadyne Industries, Inc.

Figure 27-5. *An oxyacetylene beveling machine can be used to bevel pipe.*

Joint Alignment and Fit-Up

After the joint is prepared, it must be accurately aligned and spaced. Surfaces to be welded must be clean and free of foreign matter before welding. Joint fit-up must be as consistent as possible around the circumference of the pipe. *Fit-up* is the positioning of pipe with other pipe or fittings before welding. Weld specifications and details indicate fit-up requirements. Line-up clamps are used to hold pipes or pipe and fittings securely and to ensure proper alignment during welding. The pipe may be aligned with consumable inserts, spacers, backing rings, or pipe jigs. See Figure 27-6.

Mathey Dearman

Figure 27-6. *Line-up clamps hold pipe sections securely in position while tack welds are made.*

A consumable insert provides the proper opening of the weld joint and becomes part of the weld. Consumable insert rings are used to ensure an accurate root opening before welding. Consumable insert rings are placed when the pipe is tack welded. When the root pass is deposited, the insert ring is consumed into, and becomes part of, the completed weld. Five classes and compositions of inserts are available for use as required by specific jobs. The classification numbers refer to AWS classes of consumable inserts. Class 1 is A-shaped, or inverted-T, and extends beneath both pipe on the opposite side. Class 2 is J-shaped and extends under one pipe on the opposite side. Classes 3 and 5 are rectangular. Class 4 is Y-shaped, extending to both sides on the welding side. See Figure 27-7.

Spacers may be used to provide a gap between the joint until the joint is tack welded. The spacers are removed before welding. Backing rings are commonly used in the GTAW process. Backing rings have spacers attached to a ring which fits in the pipe before welding.

Liners or backing rings can be fitted into the pipe before welding. Liners and backing rings assist in securing penetration without burning through the surface. Liners and backing rings also prevent spatter and slag from entering the pipe at the joint. Backing rings are useful in maintaining pipe alignment and preventing metal slag and spatter from entering the pipe at the joint. See Figure 27-8.

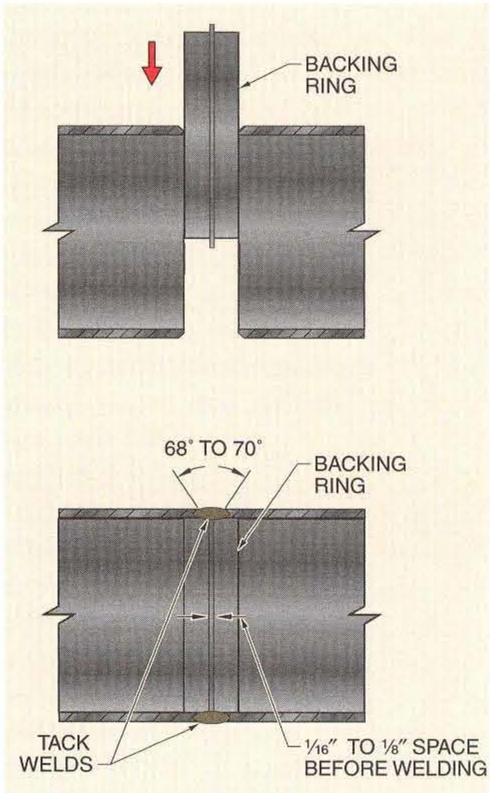


Figure 27-8. *Backing rings are fitted inside the pipe before welding and keep the sections of pipe aligned, preventing slag and spatter penetration.*

The AWS categorizes consumable inserts into five classes, which are detailed in AWS A5.30, Specifications for Consumable Inserts.

Consumable Insert Rings
Figure 27-7

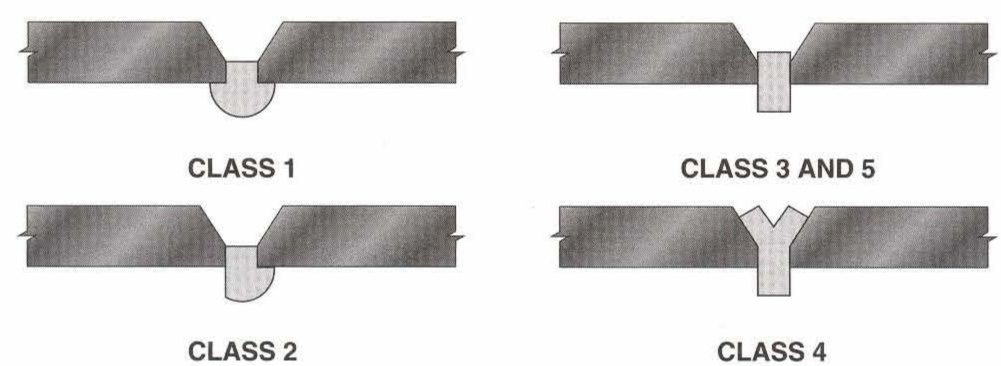


Figure 27-7. *Consumable insert rings are categorized by class and may be used to maintain an accurate root opening before welding.*

Tack welded pipes must be properly aligned before welding.

Welding is the most common method of joining pipe. Pipe welding is used for many applications including piping in commercial HVAC systems and high-pressure steam lines in nuclear power plants.

Tack Welding

A tack weld keeps the joint members from moving out of their required positions during welding. The pipes to be joined must be properly fitted and can be held in position with a pipe jig. A *pipe jig* is a device that holds sections of pipe or fittings before tack welding. Once the pipe joints are properly aligned, they are tack welded to hold the alignment during welding. For most pipe welding, four evenly spaced tack welds are made around the pipe. Tack welds should typically be about ½″ to ¾″ long. Tack welds should penetrate to the root of the groove, since they will become part of the root bead.

The root pass should completely penetrate into the root of the joint.

To make a tack weld, the electrode is inclined 10° to 15°. The arc is struck in the joint slightly ahead of where the tack weld is to be made. The arc is then quickly lengthened to stabilize it and give it time to form a protective gas shield. A sliding motion is used after the electrode has been lightly pushed into the joint. If the electrode sticks, it should be wiggled slightly but kept buried in the groove. When the tack weld is completed, the electrode is pulled away. This procedure produces a strong and fully penetrating tack weld. See Figure 27-9.

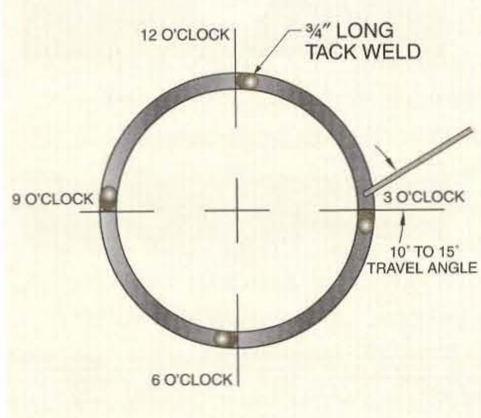


Figure 27-9. *Tack welds are used to hold properly aligned pipes in position.*

WELDING PASSES

Welding passes are used to fill the groove to the specified depth. Welding codes and standards publications specify the required depth of welds. Welding codes and specifications should be followed closely.

Most gas tungsten arc pipe welding standards require complete root penetration with uniform welds and allow for few, if any, defects. The passes used for pipe welding are the root pass, intermediate weld pass(es), and the cover pass.

Root Pass

A *root pass* is the initial weld pass that provides complete penetration through the thickness of the joint member. The current is set to provide maximum penetration without excessive weld metal deposited on the inside of the pipe.

The root pass deposits weld metal in the root of the weld as a "keyhole". The keyhole is formed by the penetration of the root pass. A properly deposited root pass (root bead) should penetrate to the root and leave a solid bead below the surface with a slight crown that does not exceed approximately $1/16''$ or the maximum allowed by the governing code. An improper root bead is cause for the entire weld to be rejected.

The success of a pipe weld depends on the correct penetration of the root bead because it forms the base upon which successive layers are made. Subsequent weld passes cannot compensate for a defective root bead.

Some undercutting may occur on the face of the groove, but undercutting is not objectionable since it will be eliminated by successive passes. See Figure 27-10.

There may be times when the root opening will vary due to poor fit-up. If the root opening is narrow, the speed of travel and electrode angle should be reduced. Where a widened root opening exists, the travel speed should be increased.

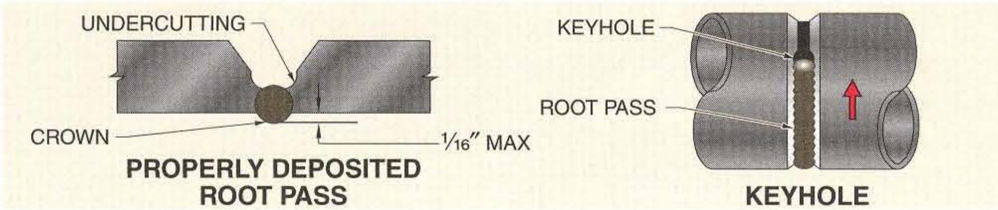


Figure 27-10. *A properly deposited root pass forms a crown on the inside of the pipe. A keyhole is formed if the root pass is stopped and must be filled when welding starts again.*

Intermediate Weld Pass(es)

An *intermediate weld pass* is a single progression of welding subsequent to the root pass and before the cover pass. In pipe welding, the first intermediate weld pass (also called the hot pass) is designed to fill the undercut caused by the root pass. It burns out particles of slag that may remain in the groove and ensures complete fusion of the base metal and the root bead. The first intermediate weld pass also eliminates the possibility of slag inclusions or porosity left from the root bead. See Figure 27-11.

The number of intermediate weld passes (or fill passes) required depends on the wall thickness, the groove angle, the size of the electrode, and the welding process used. Intermediate weld passes are deposited with large diameter electrodes and are intended to fill the weld joint. See Figure 27-12. Each intermediate weld pass penetrates completely into the previous weld bead. When intermediate weld passes are made using SMAW, the slag produced must be entirely removed after each pass.

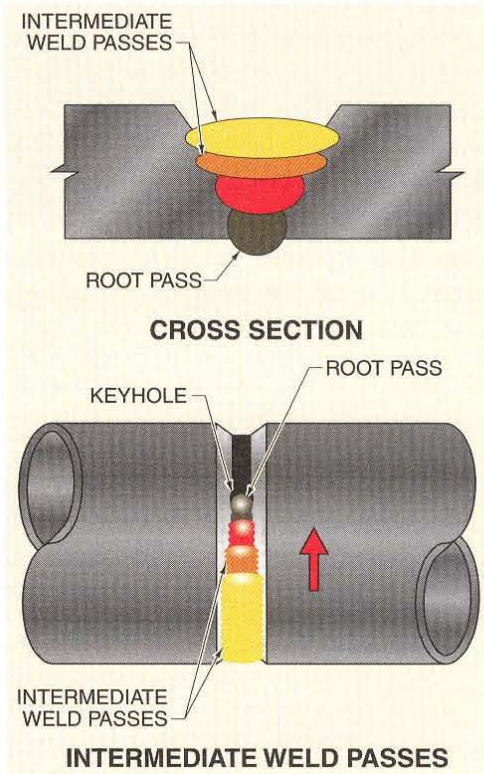


Figure 27-12. *Intermediate weld passes are used to build up the weld and fill the joint, creating a strong, sound weld.*

Intermediate weld passes are used to fill the weld joint.

The term intermediate weld pass replaces the formerly used terms hot pass and fill pass. Intermediate weld pass identifies each pass deposited after the root pass and before the cover pass.

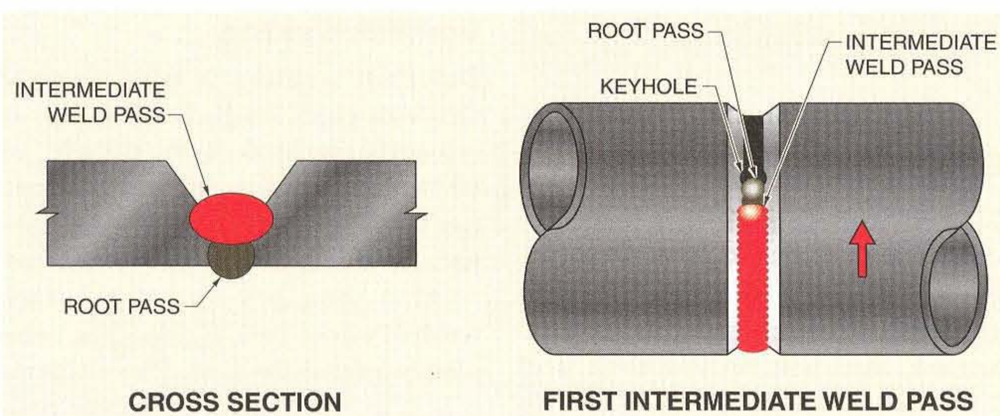


Figure 27-11. *The first intermediate weld pass fills the undercut keyhole created by the root pass.*

A pipe weld should be finished with a final cover pass.

Cover Pass

A *cover pass* is the final weld pass deposited. The cover pass provides maximum reinforcement to the weld joint and gives the weld a neat appearance. The cover pass should have a slight crown extending about 1/16" above the surface of the pipe. The cover pass is usually made using a weaving motion to provide a complete cover for and a neat appearance to the weld. A slant or semicircular motion can be used; however, it must be wide enough to cover the entire weld joint. The cover pass also provides the weld reinforcement required for strength and protection. See Figure 27-13.

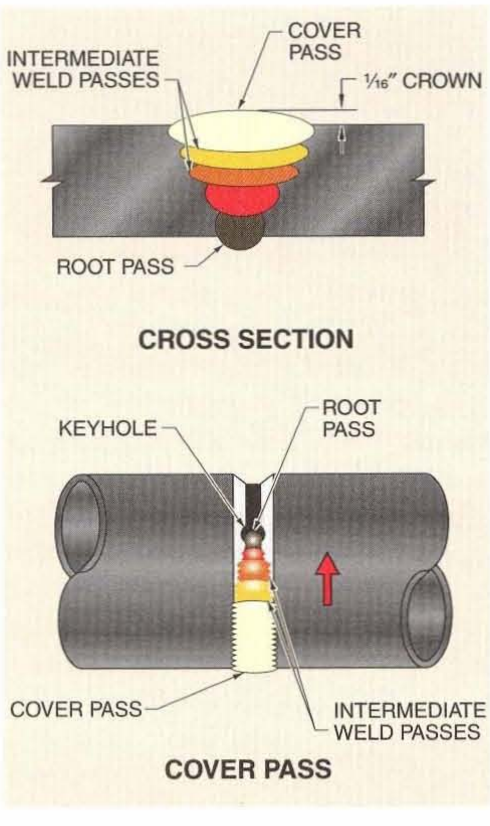


Figure 27-13. *The final cover pass adds reinforcement to the weld and provides a neat appearance. The cover pass should form a slight crown above the surface of the pipe.*

Electrodes

Most shielded metal arc pipe welding is done with E-6010 or E-6011 electrodes, except where high strength welds are required. When high strengths are needed, especially on low-alloy steel pipe, electrodes in the E-70XX series are used. See Figure 27-14.

Downhill welding should be used to weld thin-wall pipe.

RECOMMENDED ELECTRODE SIZES FOR PIPE WELD PASSES

Pass	Electrode	Current*†
Root Pass‡	5/32	140–165
Intermediate Weld Pass(es)	5/32 – 3/16	170–200
Cover Pass	3/16	160–180

* the ideal current is within the ranges shown. The best quality is obtained at the lower end of each range
† in amps
‡ Weld root pass at 24 to 26 arc volts and 10 to 16 ipm arc speed

Figure 27-14. *Electrode size is recommended based on the weld pass and required weld strength.*

PIPE WELDING TECHNIQUES

Pipe welding is recognized as a specialty within the welding trade. Although many pipe welding skills and practices are similar to other types of welding, pipe welders must develop certain techniques that are characteristic to pipe welding alone. Pipe welders have to pass certain tests to be certified because public health, environmental restrictions, and safety concerns are involved (especially in welding cross-country transmission pipelines and high-pressure lines that convey steam, oil, air, or corrosive materials). See Figure 27-15.

Pipe welding techniques vary depending on the welding conditions and the type of pipe being used. Pipe welders should be proficient in welding techniques such as, downhill welding, uphill welding, roll welding, and position welding.

Downhill Welding

Downhill welding is used to weld thin-wall pipe. Small-diameter pipe is typically welded with GTAW or GMAW. Downhill welding is preferred for welding cross-country pipelines because it is a fast welding technique.

After the pipes are securely tack welded, a root pass is deposited completely around the joint. The electrode is held in approximately the same position as when making the tack welds.

The Lincoln Electric Company

Figure 27-15. *Pipe welders must be certified in specific pipe weld joint positions.*

The arc is struck slightly ahead of the weld to preheat the area where the weld bead will be started. After the arc has stabilized, the electrode is lowered into the root opening and moved along the groove. Intermediate weld passes are usually made with a side-to-side (weaving) motion and consist only of a light bead deposit. The electrode should pause at the end of each stroke to ensure good fusion at each edge of the weld. As the electrode reaches the bottom of the weld a semicircular or horseshoe weave is used. See Figure 27-16.

Intermediate weld passes are made with the same diameter electrode used for the root bead but with slightly higher current.

For downhill welding, follow the procedure:

1. Deposit four tack welds to hold the pipe in alignment.
2. Start welding the root pass in the 12 o'clock position.
3. Carry the root pass weld downward to the 6 o'clock position.
4. Follow same procedure on the other side of the pipe. See Figure 27-17.

If the electrode sticks and fails to glide smoothly because of built-up heat, a slight side-to-side oscillating motion will usually correct the problem. After the root pass is completed, additional weld passes are deposited. The number of passes depends on the thickness of the pipe.

Intermediate Weld Pass Motions
Figure 27-16

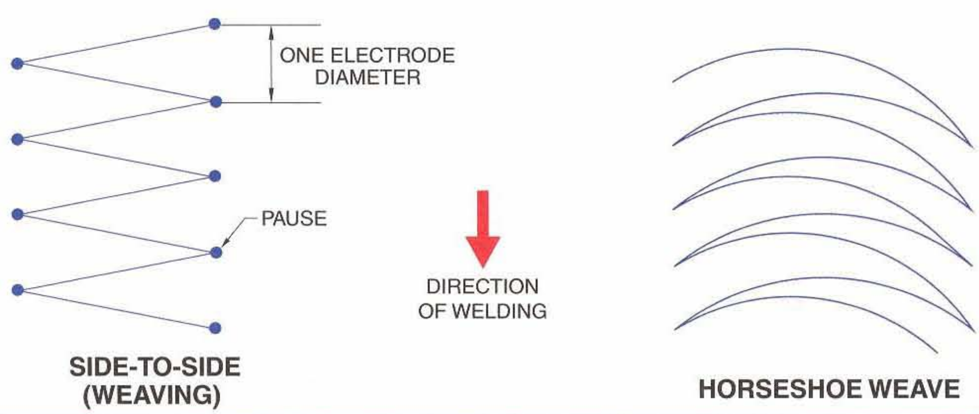
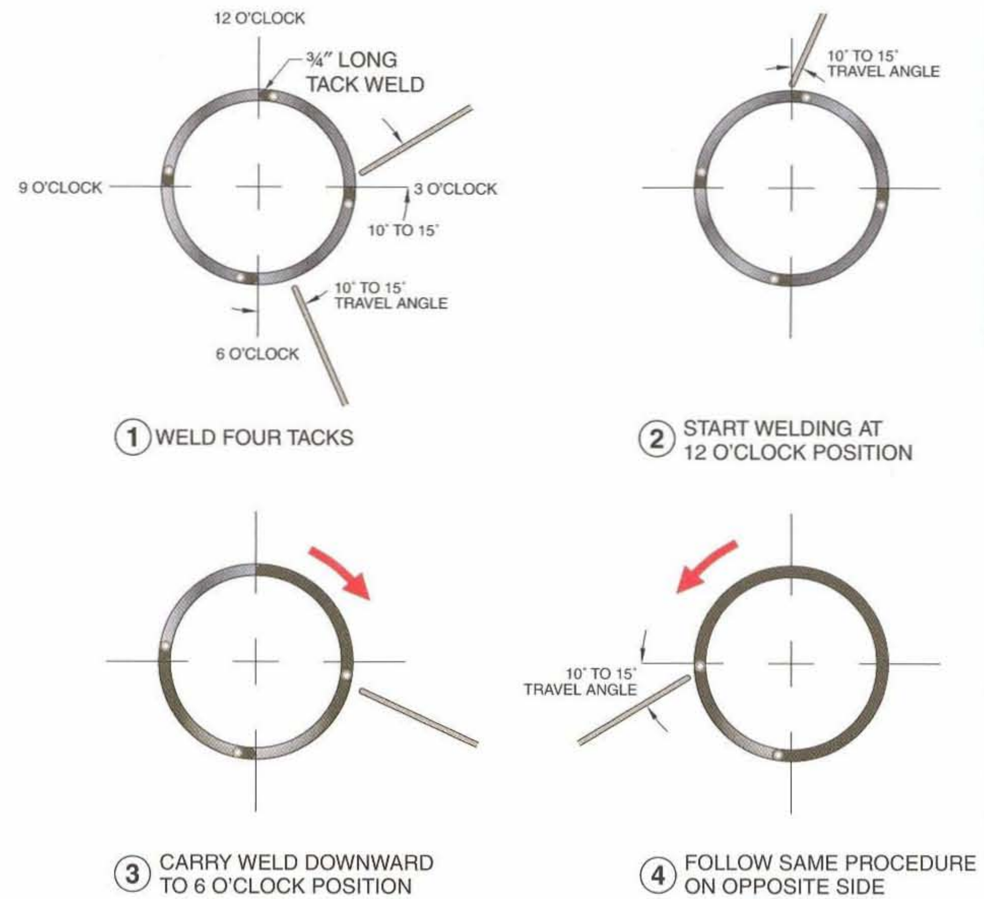


Figure 27-16. *Two motions used to make intermediate weld passes are the side-to-side (weaving) motion and the horseshoe weave.*

Figure 27-17. *Downhill welding is commonly used to weld thin-wall pipe.*

Downhill Welding
Figure 27-17



⚠ CAUTION

When restarting the arc, completely tie together the welded section with the next section.

The ends of the weld must always be tied together.

One problem encountered in downhill welding is controlling the heat input. Lack of heat input control is especially a problem when welding small-diameter pipe where heat does not dissipate fast enough and excessive heat builds up in the weld zone. Heat input can usually be regulated using a small diameter electrode and reducing the current setting.

Another problem in downhill welding is maintaining proper control of the weld pool. The molten metal tends to flow downward in the same direction the arc is moving. If the flow is not controlled, penetration cannot be achieved and slag becomes entrapped in the molten metal, producing slag inclusions in the weld. Slag inclusion is only a problem when welding with SMAW. Control of the molten weld pool is accomplished using a fast travel speed and a high-current setting to keep the arc ahead of the weld pool.

Starting and Stopping. There is a certain amount of starting and stopping during welding due to the need to change electrodes or weld position. When welding must be stopped and then restarted, the ends of each weld bead must be tied together. To restart a weld, the arc is struck about ½" back of the bead and then moved forward with a long arc. As soon as the arc is stabilized, the electrode is momentarily buried in the crater of the last bead to regenerate the molten weld pool. The electrode is then raised slightly and the weld continued. When the weld

approaches the end and must be tied into the other deposited bead, the electrode is moved up the sloping side of the previous bead, and the direction of travel is briefly reversed after the molten pool blends smoothly between the two beads. The arc is then withdrawn quickly by flicking the electrode downward and away from the center.

Uphill Welding

Uphill welding is used for welding thick-wall pipe. Welding progresses upward on one side of the pipe and then upward on the opposite side. See Figure 27-18. For uphill welding, follow the procedure:

1. Weld four tacks to hold the pipe in alignment.
2. Start welding the root pass in the 6 o'clock position.
3. Carry the weld upward to the 12 o'clock position.
4. Follow the same procedure on the opposite side.

As in downhill welding, tack welds are used to maintain alignment of the pipes. The root pass is deposited just back of the bottom, or 6 o'clock, position. The arc is struck ahead of the 6 o'clock position and a long arc is maintained for a short period to preheat the surface; then it is brought back to the weld area and welding is begun.

Uphill welding should be used on thick-wall pipe.

Uphill Welding
Figure 27-18

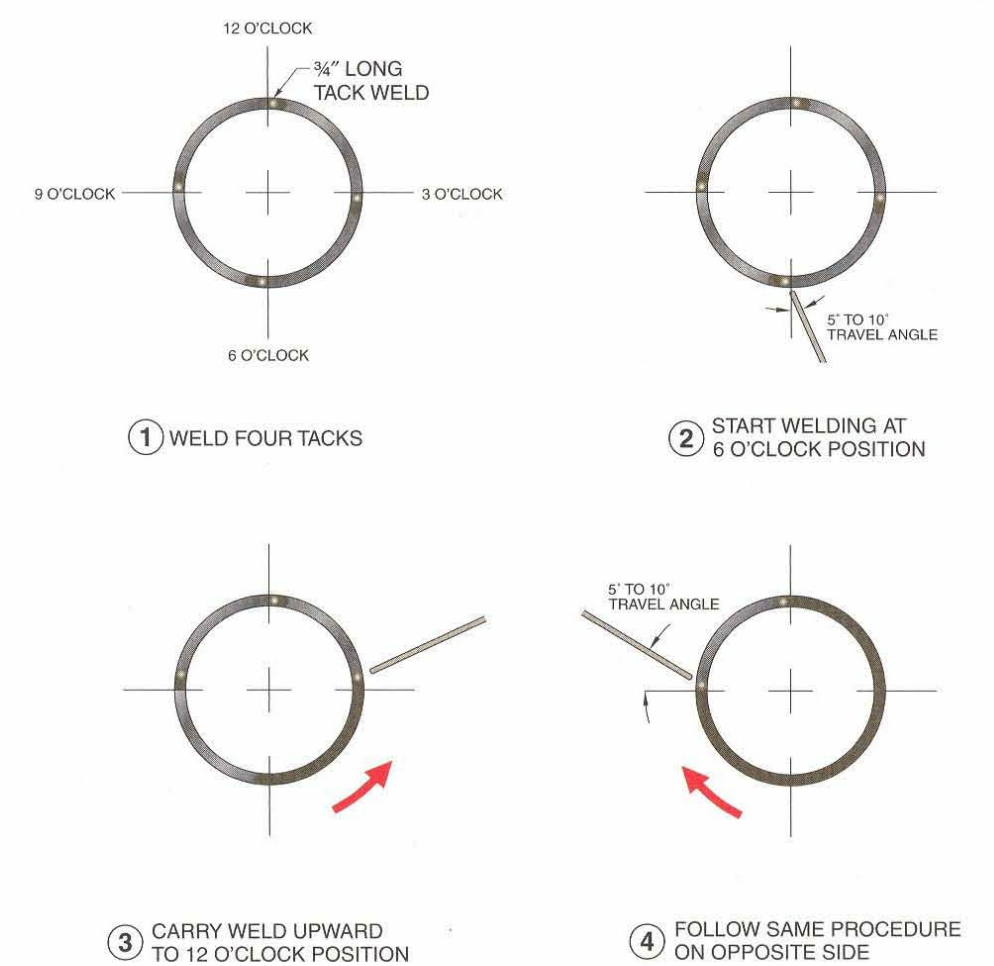


Figure 27-18. *Uphill welding is used to weld thick-wall pipe. Uphill welding starts at the 6 o'clock position and works upward on both sides of the pipe.*

In uphill welding, the root pass should be started just back of the 6 o'clock position.

While the root pass is being deposited, no electrode weaving motion is necessary. The electrode is simply advanced at an angle of 5° to 10° with a slow and uniform movement along the joint. As the electrode approaches the upper part of the pipe, the molten metal begins to flow downward at a faster rate. A slight whipping motion helps to control the weld pool and prevent metal flow.

After the root pass is completed, one or more intermediate weld pass layers are deposited followed by the final cover pass.

Roll Welding

Roll welding is a welding procedure that applies heat and pressure to interlock the faying surfaces of the weld. Roll welding is usually performed with GMAW using a hand-held welding gun. The roll welding method requires that two or more sections of pipe be lined up and tack welded. Special pipe clamps hold the pipe in alignment until they are tacked. See Figure 27-19. The weld is then completed in flat position while helpers rotate the pipe. After the short pipe sections are welded, they are placed in line with the existing or previously installed pipe and welded in a stationary position.

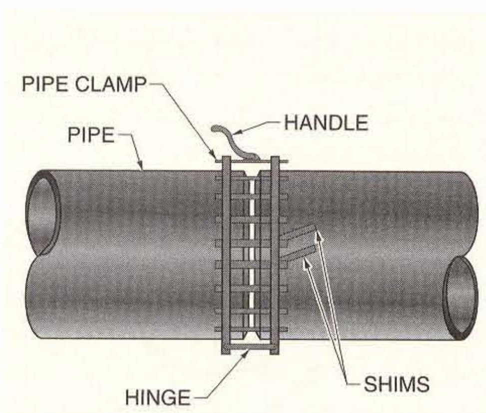


Figure 27-19. *Pipe clamps are used to hold pipe in alignment until tack welds are made.*

Position Welding

Position welding (stove pipe welding) consists of lining up each section, length by length, and welding each joint while the pipe remains stationary. Since the pipe is not rotated, the welding has to be done in various positions—flat, horizontal, vertical, and overhead. See Figure 27-20.

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Figure 27-20. *Position welding requires that the pipe be welded in various positions around stationary pipe.*

PIPE WELDING STANDARDS

Standards ensure pipe welding quality. Pipe welding standards have been established by the American Petroleum Institute (API), the American Society of Mechanical Engineers (ASME), and the American Welding Society (AWS) for specifying material requirements, preparation, welder proficiency, and weld testing. Other agencies may adopt these standards for specific applications. For example, the U.S. Department of Defense has adopted several standards published by the AWS.

Welder Certification

Certification of welders is based on the proficiency of the welder making welds in specific positions. Pipe weld joint positions are identified as test positions. Because pipe welds are usually groove welds, they are identified by the letter G, for groove weld. Test positions are 1G, 2G, 5G, 6G, and 6GR. There is no 3G or 4G test position in pipe welding. The axis of the pipe may vary ±15° for the 1G, 2G, and 5G test positions, but only ±5° for the 6G and 6GR positions. See Figure 27-21.

AWS Pipe Weld Test Positions
Figure 27-21

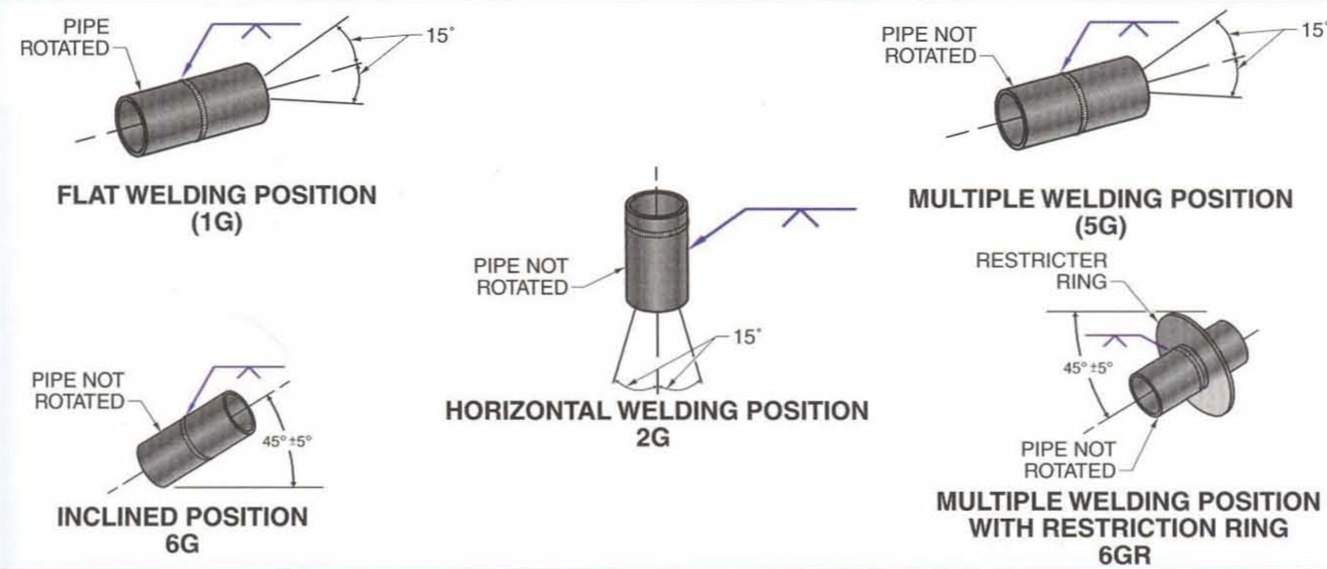


Figure 27-21. *The American Welding Society (AWS) has identified weld positions for pipe and tubing welding as test positions 1G, 2G, 5G, 6G, and 6GR.*

1G Position. Test position 1G is the flat welding test position. The axis of the pipe is in horizontal position. The axis of the weld is in flat position. The weld is completed in flat position as the pipe is rotated. The axis of the pipe should be within 15° above or below the horizontal. Test position 1G qualifies a welder to weld in flat position.

2G Position. Test position 2G is the horizontal position. The axis of the pipe is in vertical position and the axis of the weld is in horizontal position. The weld is completed in vertical position. The axis should be within 15° on any side of vertical. Test position 2G qualifies a welder to weld in flat and horizontal positions.

5G Position. Test position 5G is the multiple welding test position. The axis of the pipe is in horizontal position. The axis of the weld is in vertical position, but the pipe is not turned or rolled during welding. The weld is completed in flat, vertical, or overhead fixed positions. The axis should be within 15° above or below the horizontal. Test position 5G qualifies a welder to weld in flat, vertical, and overhead positions.

6G Position. Test position 6G is the inclined position. The pipe is fixed in position and is not rotated during welding. The weld is completed with the axis of the pipe at a 45° angle ±5°. The axis of the pipe is set and the pipe is not rotated while welding.

6GR Position. Test position 6GR is multiple position welding with a restriction ring. Restricted accessibility is often added by placing a restriction ring near the weld. Test position 6GR requires the axis of the pipe to be positioned at a 45° angle, ±5°. The pipe is fixed in position and is not rotated during welding.

WELDING METHODS

Welding methods used for pipe are the same as are used for other welding processes. The method used depends on the pipe material, diameter, and function of the piping system. The composition of the pipe determines the filler metal and welding process used. For example, welding stainless steel pipe with a ⅜″ wall thickness requires deep penetration. Pipe in a critical application may be purged with shielding gas. GTAW is used to ensure weld purity.

Most pipe welding jobs require that the welder be certified.

Most pipe welding is done with either SMAW or GMAW. The advantage of GMAW over SMAW is that with GMAW, no slag occurs in the weld. Also, the gas protection shield over the weld area prevents atmospheric contamination of the weld. Since GMAW requires no slag removal, less welding time is required. There is no significant difference in welding techniques and procedures between SMAW and GMAW. General descriptions of pipe welding processes apply to both SMAW and GMAW.

GTAW may be used when shop welding small-diameter pipes. GTAW is also sometimes used to deposit the root bead of large-diameter pipe jobs. Pipe welding is commonly performed using manual, semiautomatic, mechanized, or automatic welding.

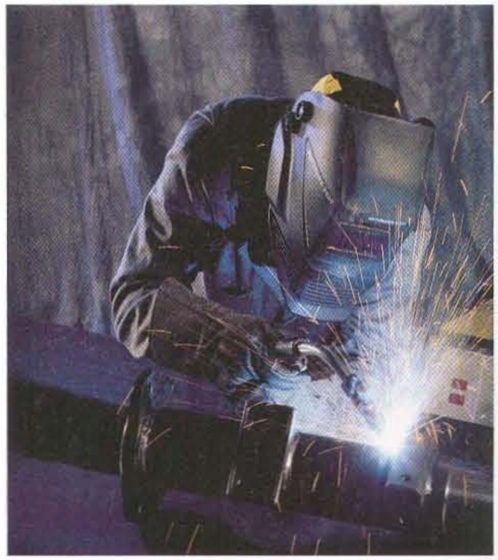
Manual Welding

Manual welding is welding with a torch, welding gun or electrode holder, held and manipulated by hand. Manual welding using OAW was commonly used for many years to weld pipe. It worked well for thin-wall pipe, but thick-wall pipe required too much time and was difficult to weld. Although not commonly used, some thin-wall pipe is still welded with OAW.

SMAW is a manual welding process commonly used for welding pipe because of the flexibility and mobility of the equipment, and the accessibility to the weld area.

Semiautomatic Welding

Semiautomatic welding is manual welding with equipment that controls one or more welding conditions automatically. Semiautomatic welding requires a welder to manually weld while equipment controls one or more welding condition(s). A constant voltage welding machine provides the power and a wire feeder delivers the electrode to the weld pool while the welder controls the welding gun manually. See Figure 27-22. Common semiautomatic welding processes are GMAW and FCAW.



ESAB Welding and Cutting Products

Figure 27-22. *Gas metal arc welding is often used to join small-diameter pipe while the welder controls the welding gun.*

Mechanized Welding

Mechanized welding is a welding process in which the welding process is automatic, but the operator must make process adjustments manually. In mechanized welding, the machine controls the welding gun. The welding gun moves along the weld at a set height. If the seam is not flat or straight, the operator must adjust the equipment. The operator must observe the progress of the welding gun or electrode holder and make adjustments as necessary.

Automatic Welding

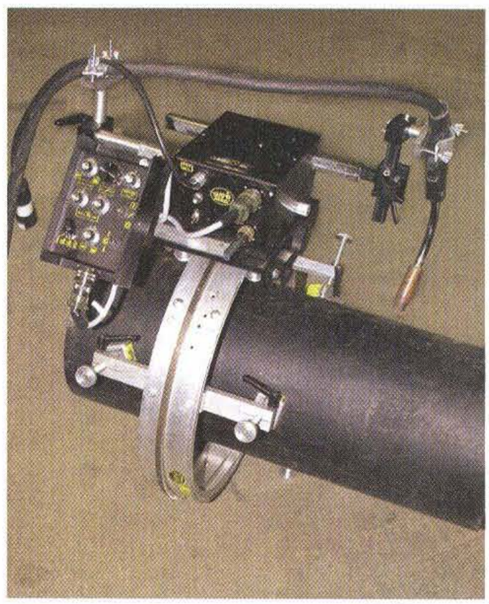
Automatic welding is a welding process that requires minimal observation of the welding process by the operator and no manual adjustment of the controls. The welding equipment automatically controls one or more welding condition(s). The automatic welding system monitors the arc voltage and adjusts the height of the welding gun from the base metal to maintain a

consistent distance and a quality weld. Most large diameter (24″ and over) pipe is welded using an automatic GMAW process.

Automatic GMAW machines speed up the welding process and produce welds without slag inclusions, which are a constant problem with SMAW. Unlike conventional pipe welding procedures where the root bead is deposited externally, in automatic welding the root pass is deposited inside the pipe. A special bevel is made on the pipe for this purpose. See Figure 27-23. Usually, four welding heads mounted on an internal line-up clamp are used to make the internal root bead in a single pass.

The internal welding unit is self-propelled along the inside of the pipe and held in place at the weld site by clamp shoes. Welding heads are positioned precisely over the joints by means of special aligner blocks. Once the unit is correctly positioned, the next section of pipe is slipped over the reach rod of the unit. The joint is properly spaced and another set of clamp shoes is actuated to hold the joint in place for welding. A control box mounted on the handle of the reach rod controls the starting and stopping of welding. Each welding head welds a 90° arc. All welds are made downhill with two heads moving clockwise and the other two moving counterclockwise. Shielding gas for internal welding consists of 75% argon and 25% CO_2.

External Welding. The external welding process includes a root pass, intermediate weld pass, and cover pass. Passes are made with special welding units that travel around the external perimeter of the pipe on pre-positioned circumferential pipe bands. Two welding machines, sometimes referred to as bugs, move simultaneously on the pipe. See Figure 27-24. One bug starts at the 12 o'clock position and travels downward to 6 o'clock. The other bug starts at the 3 o'clock position and stops at the 9 o'clock position. The bug is then moved to the 12 o'clock position to complete the pass at the horizontal. External welds are made with 100% CO_2 because it has a higher deposition rate and better penetrating qualities.



Weld Tooling Corp.

Figure 27-24. *External welding bugs are used to make intermediate and cover passes while positioned outside the pipe.*

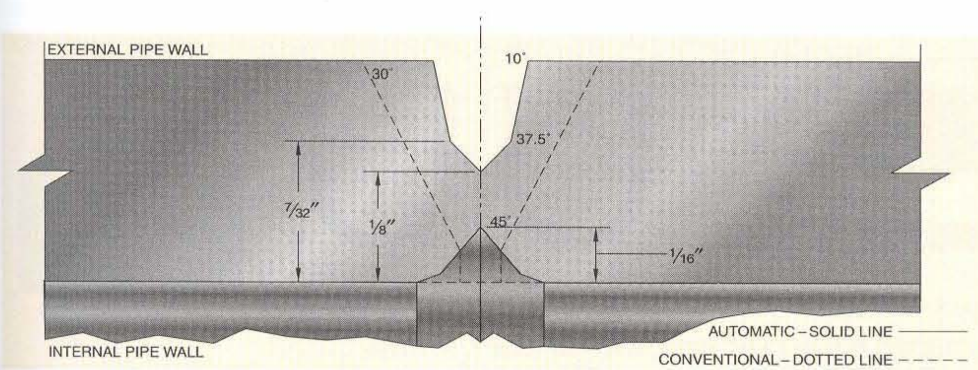


Figure 27-23. *The bevel on a pipe can be adapted for automatic welding to allow for differences in penetration of the welds.*

PIPE WELD TESTING

Pipe weld testing can be conducted using nondestructive examination and destructive testing. Testing methods for pipe are similar to those used for other types of metals.

Destructive Testing

Destructive testing is used primarily in the qualification of welding procedures and are often used to test welder performance. In destructive testing, a test specimen is analyzed using the tensile test or the guided bend test. A test specimen is a section of welded metal that includes the weld area. In the tensile test, the test specimen is subjected to force in opposite directions. The tensile strength achieved is compared with weld strength requirements. See Figure 27-25. In the guided bend test, a test specimen is used in a guided bend tester to identify points of failure when the test specimen is subjected to a bending force. The guided bend test requires two test specimens, a face bend specimen and a root bend specimen.

Destructive Testing
Figure 27-25

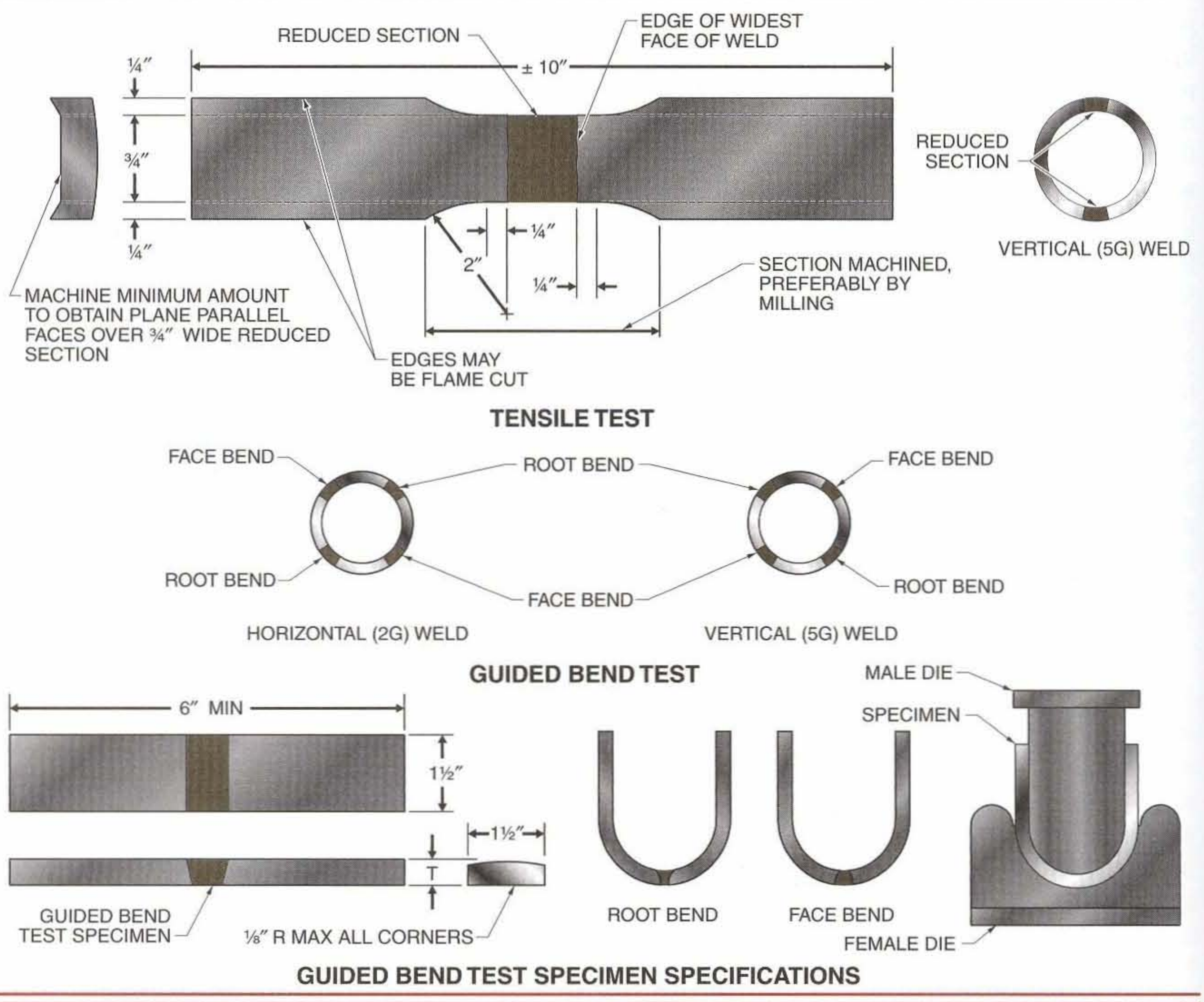


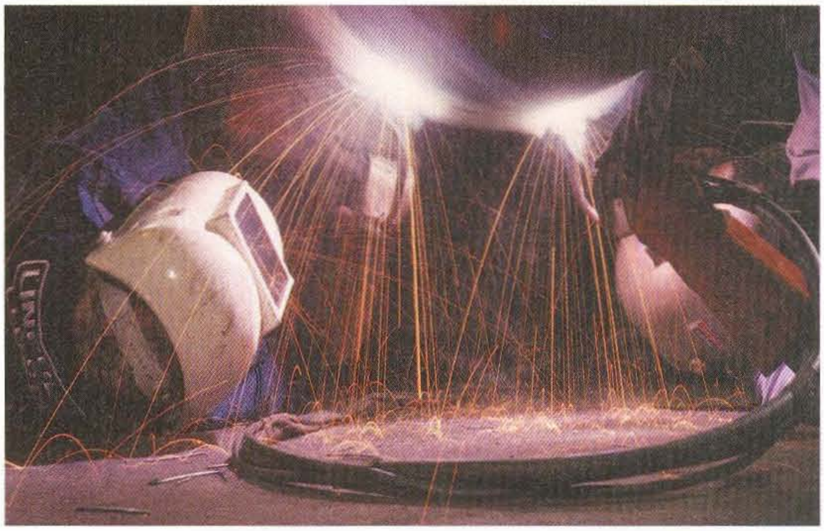
Figure 27-25. *Tensile and guided bend tests are used for destructive testing of pipe welds.*

The face-bend specimen is checked for incomplete penetration, porosity, inclusions, or other defects. The specimen is placed in the guided bend tester with the face side down. The root-bend specimen is tested for complete penetration. The specimen is placed in the guided bend tester with the root side down. After bending, the test specimen is inspected for cracks.

Nondestructive Examination

Nondestructive examination (NDE) is the development and application of methods to examine materials or components in ways that do not impair their usefulness or serviceability.

Nondestructive examination is used to determine weld quality without affecting performance of the weld. Nondestructive examination methods include liquid penetrant, radiographic, ultrasonic, and visual examination. See Figure 27-26.



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A welder must be able to weld pipe from various positions around the pipe since most pipe cannot be rotated.

NONDESTRUCTIVE EXAMINATION

Method	Letter Designation
Acoustic emission	AET
Electromagnetic	ET
Leak	LT
Magnetic particle	MT
Neutron radiographic	NRT
Liquid penetrant*	PT
Proof*	PRT
Radiographic*	RT
Ultrasonic*	UT
Visual*	VT

*methods used for testing pipe welds

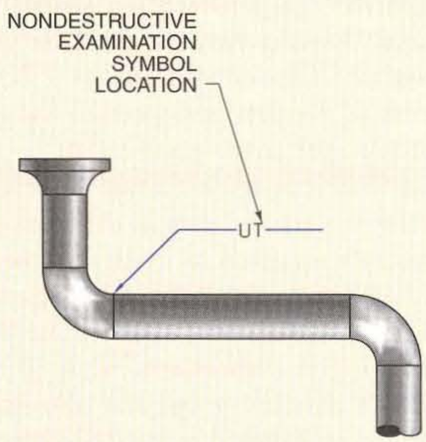


Figure 27-26. *Nondestructive examination does not adversely affect the performance of the weld.*

POINTS TO REMEMBER

1. Small-diameter pipe with a wall thickness of less than ⅛″ is typically not beveled.
2. Tack welded pipes should be properly aligned before welding.
3. The root pass should completely penetrate into the root of the joint.
4. Intermediate weld passes are used to fill the joint.
5. A pipe weld should be finished with a final cover pass.
6. Downhill welding should be used to weld thin-wall pipe.
7. Uphill welding should be used on thick-wall pipe.
8. In uphill welding, the root pass should be started just back of the 6 o'clock position.
9. The ends of the weld must always be tied together.
10. Most pipe welding jobs require that the welder be certified.

QUESTIONS FOR STUDY AND DISCUSSION

1. How is thin-wall pipe distinguished from thick-wall pipe?
2. As a rule, how many tack welds are made on pipe?
3. What is the function of a backing ring?
4. If the electrode sticks in the groove when making a tack weld, what should be done?
5. Why is a proper root opening very important in pipe welding?
6. What is a root pass?
7. What is the function of the first intermediate weld pass?
8. What is the function of the cover pass?
9. Why is a whipping action of the electrode sometimes used?
10. Why should each layer start and stop at different points?
11. What electrode motions are used to make intermediate weld passes?
12. The external welding process includes what passes?
13. Which electrodes are used for most shielded metal arc pipe welding?
14. How is welding performed when started at the 6 o'clock position?
15. What is the difference between uphill and downhill welding?
16. What are some of the problems that may be encountered in downhill welding?
17. Downhill welding is used for welding what kind of pipe?
18. How are the ends of a weld tied together?
19. At what angle should the electrode be held for downhill welding?
20. What is the starting position for thin-wall pipe welded with the downhill technique?
21. Why do pipe welders usually have to meet certification requirements?

Production Welding

28

Other Welding Processes

Production welding refers to welding techniques used in the fabrication of goods in mass production. Industries involved in manufacturing use welding processes that allow the joining of metal rapidly and automatically. Since production techniques depend on the nature of the goods made, the welding process and equipment used vary from one industry to another.

Special welding machines are often designed for a particular industry. An aircraft company may need a spotwelder designed to join certain types of aluminum structures, while an automotive manufacturer may require a resistance-type seam welder specially made to weld structural steel. Other applications may require a stud-welding gun to fasten studs on metal components.

Welding processes used for production welding include resistance welding (RW), gas metal arc welding (GMAW), stud welding, electron beam welding (EBW), friction welding (FRW), laser beam welding (LBW), plasma arc welding (PAW), submerged arc welding (SAW), ultrasonic welding (USW), electrogas welding (EGW), and adhesive bonding (AB). Other welding processes that may be used for production welding are explosion welding (EXW), forge welding (FOW), roll welding (ROW), and cold welding (CW).

RESISTANCE WELDING

Resistance welding (RW) is the most commonly used of the production welding processes. *Resistance welding (RW)* is a group of welding processes in which fusion occurs from the heat obtained by resistance to the flow of welding current through the metals joined. All RW processes are based upon the following fundamental principles:

- Heat is generated by the resistance of the workpieces to be joined to the passage of a heavy electrical current.
- The heat at the juncture of the workpieces changes the metal to a plastic state.
- When the workpieces, heated to a plastic state, are combined with the correct amount of pressure, fusion takes place.

RW machinery is similar whether the machine is a simple or complex design. The main difference is the type of jaws or electrodes that hold the object to be welded. See Figure 28-1. A standard resistance welder has four principal elements:

- The frame is the main body of the machine, which differs in size and shape for stationary and portable types.
- The electrical circuit, which includes a step-down transformer that

Spot welding is a form of RW with wide application in industry.

reduces voltage and proportionally increases current to provide the necessary heat at the point of welding.

- The electrodes include the mechanism for making and holding contact at the weld area.
- The timing controls use switches that regulate the amount of current, current duration, and the contact period.

The most common types of RW are spot welding, seam welding, projection welding, multiple-impulse welding, flash welding, and upset welding.

Spot Welding

Spot welding is the most commonly used RW process. The material to be joined is placed between two electrodes, pressure is applied, and a charge of electricity is sent from one electrode, through the material, to the other electrode.

There are three stages in making a spot weld. First, the electrodes are brought together against the metal and pressure is applied before the current is turned ON. Next, the current is turned ON for a short time. The third step is the hold time, in which the current is turned OFF but the pressure continues. The hold time fuses the metal while it is cooling.

Spot welding usually leaves slight depressions on the metal that are undesirable on the "show side" of the finished product. Depressions can be minimized using large-diameter electrode tips on the "show side".

Spotwelders are made for both direct current and alternating current. The amount of current must be controlled. Too little current produces a light tack and provides insufficient strength to the weld. Too much current causes excessive heat.

To dissipate the heat and cool the weld as quickly as possible to prevent overheating, the electrodes that conduct the current and apply the pressure for spot welding are water-cooled. The electrodes are made of low-resistance copper alloy and are usually hollow

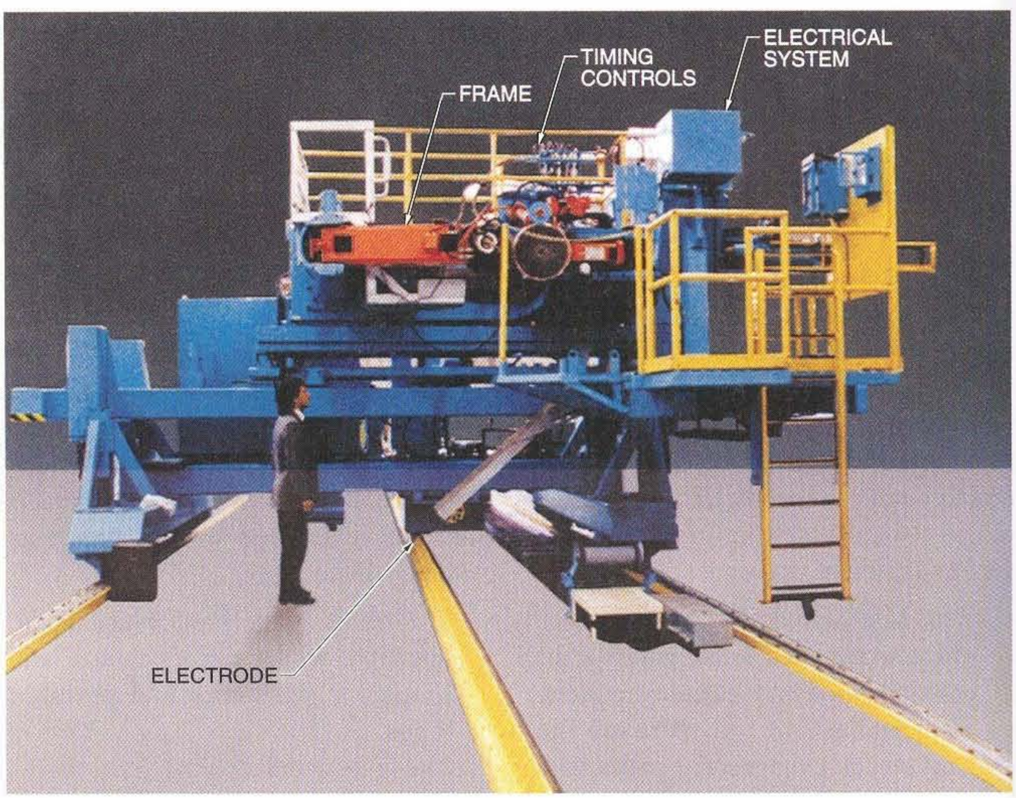


Figure 28-1. *RW machinery is similar whether the machine is a simple or complex design.*

Pandjiris, Inc.

to facilitate water-cooling. Electrodes must be kept clean and in the correct shape to produce good results. For example, if a 1/4" dia. electrode face is allowed to increase to 3/8" by wear or mushrooming, the contact area is doubled and, correspondingly, the current density decreases. A current density decrease results in weak welds unless the decrease is compensated for by an increase in current setting. Additional factors that cause poor welds are misalignment of electrodes, improper electrode pressure, and convex or concave electrode surfaces.

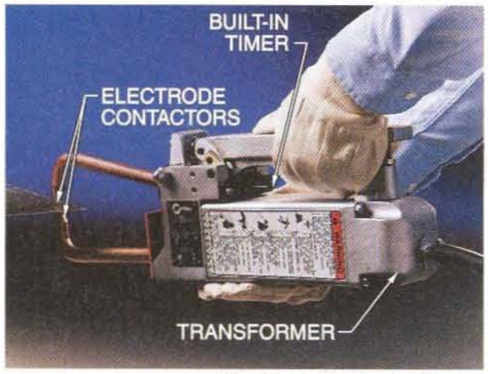
Two basic types of spotwelders are single-spot and multiple-spot. A single-spot has two long horizontal horns, each holding a single electrode, with the upper arm providing the moving action.

Multiple-spot spotwelders have a series of hydraulic- or air-operated welding guns mounted in a framework or header but use a common (or bar) mandrel for the lower electrode. The guns are connected by flexible bands to individual transformers or to a common busbar attached to the transformer. Two or four guns can be attached to a transformer.

Although many spotwelders are stationary, portable spotwelders are becoming more popular. A portable spotwelder, or spot-welding gun, consists of a welding head connected to the transformer by flexible cables. The jaws of the welding head can be operated manually, pneumatically, or hydraulically.

The self-contained portable spotwelder contains a built-in timer, electrode contactors, and transformer, and requires only a 115 V power connection. See Figure 28-2. With this apparatus, spot welds can be made on irregularly shaped objects. A self-contained portable spotwelder is especially suitable for sheet metal and auto body welding.

Portable Spotwelders
Figure 28-2



Miller Electric Manufacturing Company

Figure 28-2. *A self-contained portable spotwelder contains a built-in timer, electrode contactors, and a transformer.*

Spotwelders are available to produce single-spot welds or multiple-spot welds.

Spotwelders are used extensively for welding steel. When equipped with an electronic timer, spotwelders can be used for other commercial metals such as aluminum, copper, and stainless steel. They are also very effective for welding galvanized metal.

Seam Welding

Seam welding produces a series of overlapping spot welds, thereby making a continuous-weld seam.

Seam welding is similar to spot welding except that the welds overlap, making a continuous weld seam. In seam welding, the metal pieces pass between roller-type electrodes. As the electrodes revolve, the current is automatically turned ON and OFF at intervals corresponding to the speed at which the parts move. With proper control, it is possible to obtain airtight seams suitable for containers such as barrels, water heaters, and fuel tanks. When an intermittent current is used and the spot welds are not overlapped long enough to produce a continuous weld, the process is referred to as roller spot welding. See Figure 28-3.

Seam welding is an effective welding method because of its short current cycle. The rollers may be cooled to prevent overheating, with consequent wheel dressing and replacement problems reduced to a minimum. Cooling is accomplished by internally circulating

water or by an external spray of water over the electrode rollers. See Figure 28-4.

Since the heat input is low, very little of the welded area is hardened, and the yield point is not materially affected. Very little grain growth takes place during seam welding, which makes seam welding applicable to corrosion-resistant alloys such as ferritic stainless steels and other ferritic stainless steels whose metal properties are modified by grain growth.

Seam Welding
Figure 28-3

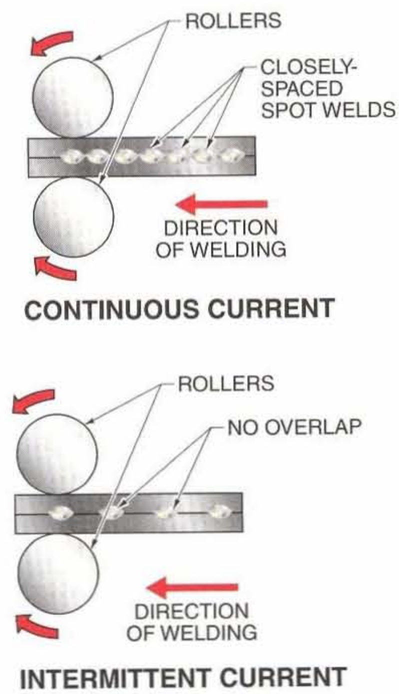
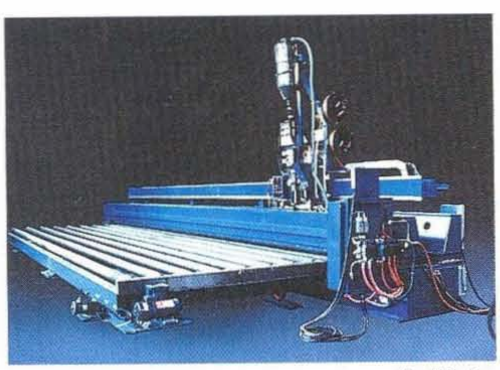


Figure 28-3. *In a continuous spot weld, welds must be closely spaced to provide an airtight seam. In intermittent spot welding, a seam weld is produced in which the spot welds are spaced apart.*



Pandjiris, Inc.

Figure 28-4. *Seam welding is an advantageous welding method because of its short current cycle. The rollers may be cooled to prevent overheating.*

Projection Welding

Projection welding (PW) is a welding process that produces a weld using heat obtained from resistance of the workpiece to the welding current. The PW process is similar to spot welding. The point where welding is to be performed has one or more projections that have been formed by embossing, stamping, casting, or machining. The PW process consists of placing the projections in contact with the workpiece and aligning them between the electrodes. See Figure 28-5. The projections serve to concentrate the welding heat at the weld area and cause fusion without requiring high current. Single or multiple projections can be welded simultaneously.

Projection Welding
Figure 28-5

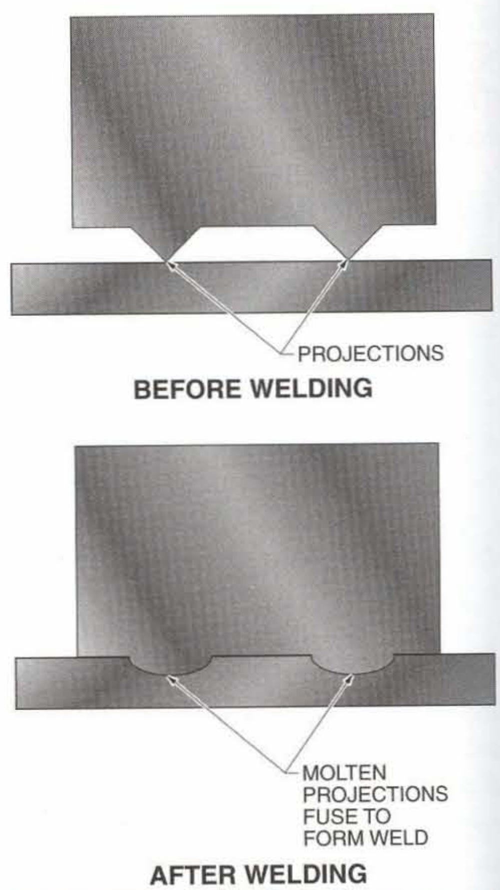


Figure 28-5. *In PW, projections concentrate heat from the resistance to the welding current.*

There are many variables involved in PW such as metal thickness, type of metal, and number of projections, which make it impossible to predetermine the correct current setting and pressure required. Only by trial runs followed by careful inspection can proper control settings be established.

Not all metals can be welded with PW. Brass and copper do not lend themselves to PW because brass and copper projections usually collapse under pressure. Aluminum PW is limited to extruded parts (shapes formed by forcing metal through a die). However, galvanized iron and tin plate, as well as most other light-gauge steels, can be successfully welded with PW. PW is also widely used for attaching fasteners to structural members.

Multiple-Impulse Welding
Figure 28-6

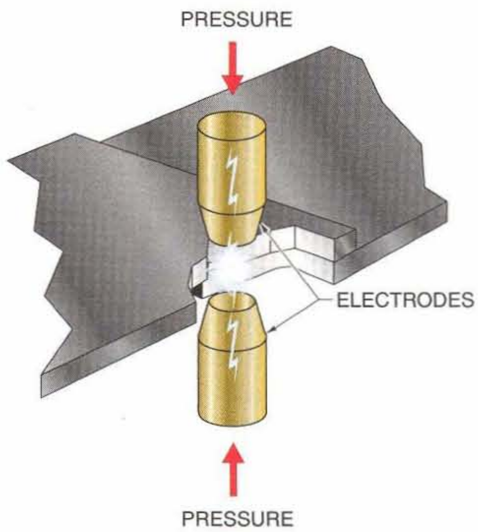


Figure 28-6. *In multiple-impulse welding, the current is regulated by precise electronic control.*

PW is widely used in attaching fasteners to structural members.

Multiple-Impulse Welding

Multiple-impulse welding is a form of resistance welding in which welds are made with repeated electrical impulses. In regular spot welding, interruption of the flow of welding current is controlled manually; with multiple-impulse welding the current is regulated electronically to go on and off a given number of times during the making of one weld. See Figure 28-6. Multiple-impulse welding permits thicker materials to be spot-welded. The interrupted current helps keep electrodes cooler, minimizing electrode distortion and reducing the tendency of the weld to spark, as well as increasing the life of the electrode.

Flash Welding

Flash welding (FW) is a resistance welding process that produces a weld at the faying surfaces of a joint by the intense heat of an arc that occurs when the workpieces are contacted and by the application of pressure after heating. The weld is completed by a rapid upsetting of the workpieces.

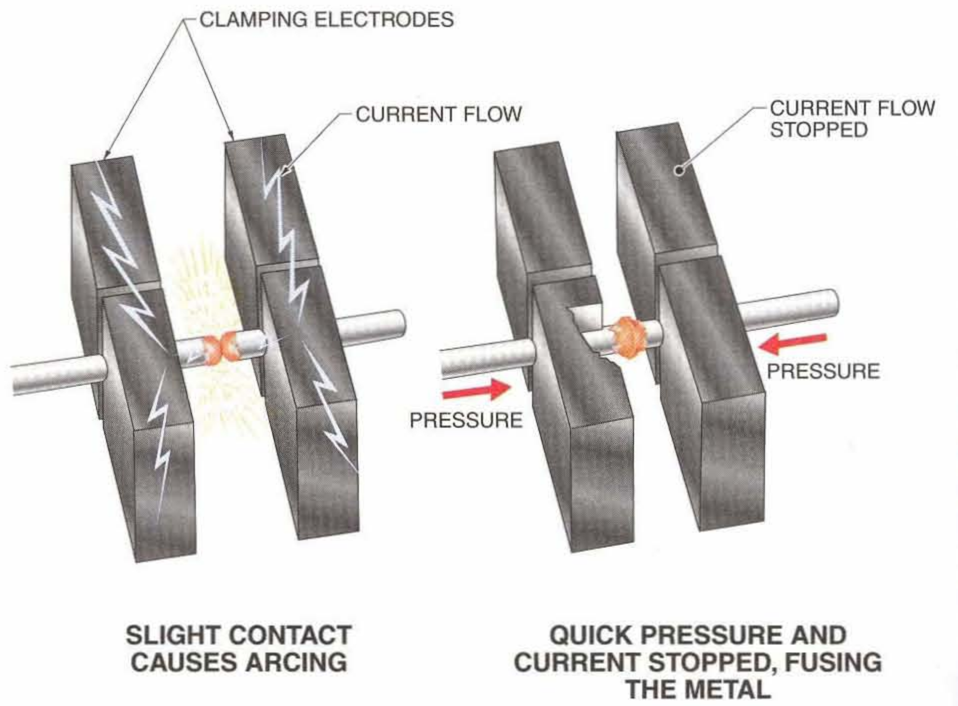
The workpieces to be joined are clamped in copper alloy dies shaped to fit each piece that conducts the electric current to the work. The ends of the two workpieces are moved together until an arc is established. The flashing action across the gap, caused by very high current densities at small contact points between the workpieces, melts the metal, forcibly expels material from the joint, and creates fusion as the two molten ends are moved together. See Figure 28-7. The current is turned OFF as soon as the fusing action is completed. For some operations the dies are water-cooled to dissipate the heat from the welded area. Parts to be flash welded must be precisely aligned. Misalignment results in a poor joint and produces uneven heat and telescoping of one piece over another.

In multiple-impulse welding, the current is regulated to go on and off a number of times during the welding process.

FW is used to butt- or miter-weld sheet, bar, rod, tubing, and extruded sections. It has almost unlimited application for both ferrous and nonferrous metals, but it is not generally recommended for welding cast iron, lead, or zinc alloys.

Figure 28-7. *In FW, an intense arcing—caused by the electrical current flowing through the two workpieces being brought together—melts the metal and creates fusion.*

Flash Welding
Figure 28-7



A problem in FW is the bulge (flash) or increased size that results at the weld. If the profile of the finish area of the weld must be smooth, then the flash must be removed by grinding or machining after welding.

Upset Welding

Upset welding (UW) is a resistance welding process that produces a weld on the faying surfaces by the heat obtained from resistance to the flow of current through the surface contact areas while under constant pressure. The metals to be welded are brought into contact under pressure, an electric current is passed through them, and the edges are softened and fused together.

UW differs from FW in that constant pressure is applied during the heating process, which eliminates flashing. The heat generated at the point of contact results entirely from resistance. Although the operation and control of the UW process is almost identical to FW, the basic difference is that less current is used and more time must be allowed for the weld to be completed. See Figure 28-8.

GAS TUNGSTEN ARC SPOT WELDING

Gas tungsten arc spot welding is an arc welding process that produces localized fusion similar to resistance spot welding but does not require accessibility to both sides of the joint. The gas tungsten arc spot welding process has many applications in fabricating sheet-metal products with joints that cannot be welded using RW because of the location of the weld, the size of the parts, or where welding can be made from only one side. Gas tungsten arc spot welding provides a deeper, more localized penetration compared to conventional RW. See Figure 28-9. Heat is generated from resistance of the work to the flow of electrical current in a circuit of which the work is a part.

Upset Welding
Figure 28-8

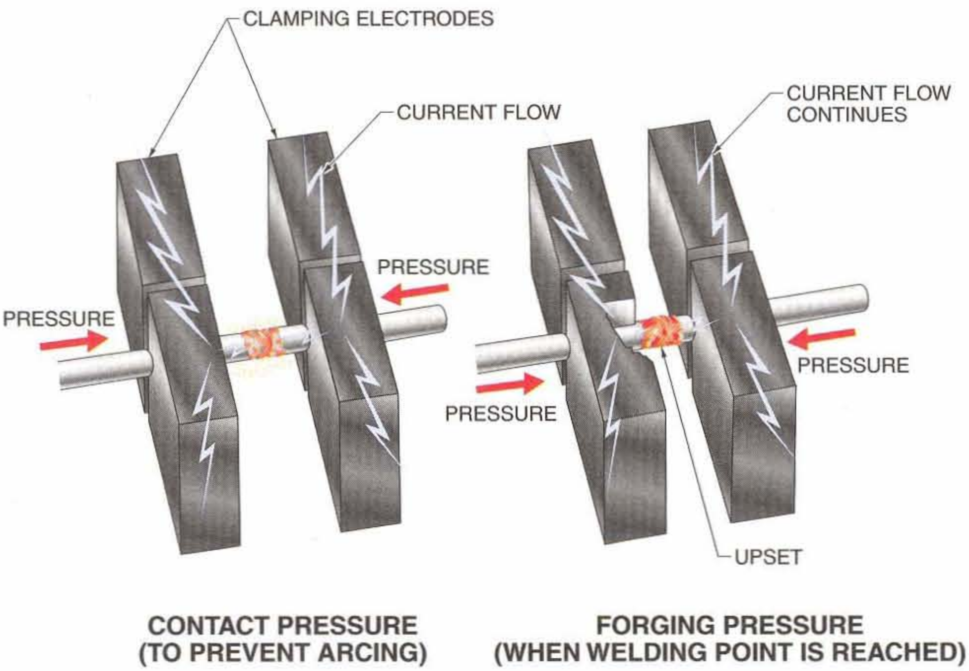


Figure 28-8. *UW involves passing high current through the workpieces while continuous pressure is applied.*

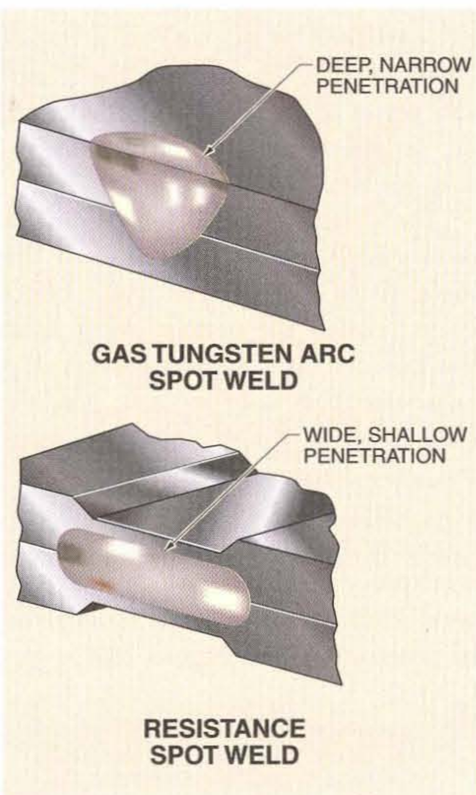


Figure 28-9. *Gas tungsten arc spot welding provides a deeper and more localized penetration compared to that obtained by conventional resistance welding.*

Gas Tungsten Arc Spot Welding Equipment

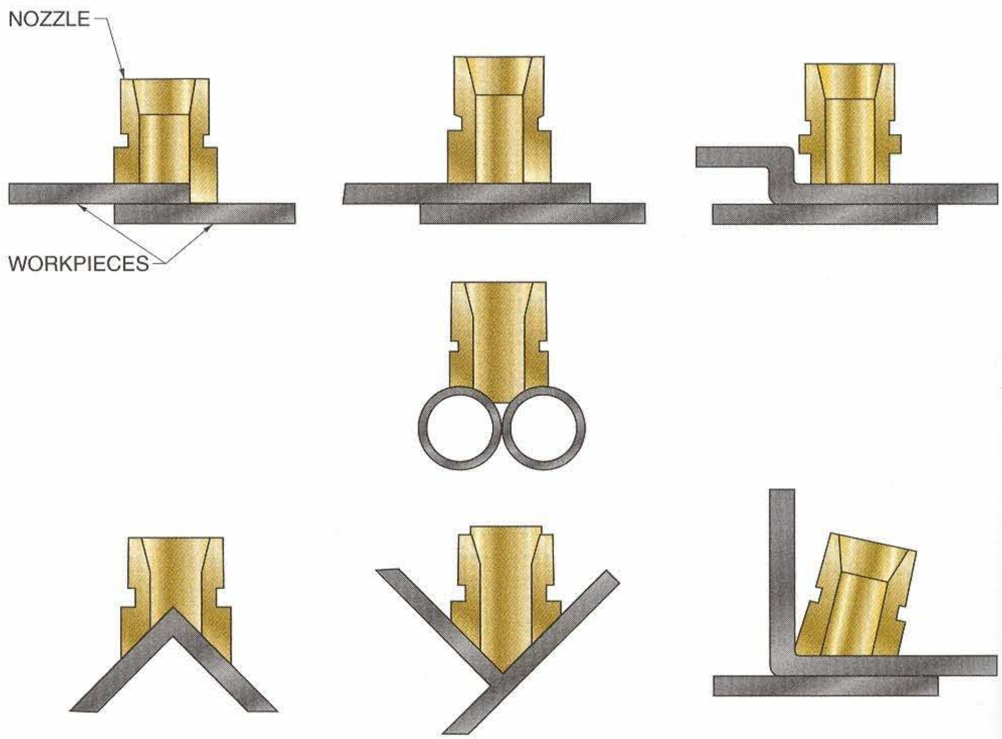
Any DC welding machine that provides up to 250 A with a minimum open circuit voltage of 55 V can be used for gas tungsten arc spot welding.

The tungsten arc welding gun has a nozzle that holds a tungsten electrode. Various shapes of nozzles are available to meet particular job requirements. See Figure 28-10. The standard nozzle can also be machined to permit access in tight corners or its diameter reduced to weld on items such as small holding clips.

For most operations, a 1/8″ diameter electrode is used. The end of the electrode should normally be flat and of the same diameter as the electrode. However, when working at low current settings (100 A or less), better results are obtained if the end of the electrode is tapered slightly to provide a blunt point approximately one-half

Figure 28-10. *The gas tungsten arc spot welding nozzle can be shaped or machined for a variety of welding jobs.*

Gas Tungsten Arc Spot Welding Nozzles
Figure 28-10



When gas tungsten arc spot welding, set the current based on the thickness of the metal to be spot welded.

the diameter of the electrode. The blunt point helps to prevent the arc from wandering. If the end of the electrode balls excessively after only a few welds have been made, it is usually an indication of excessive current, dirty material, or insufficient shielding gas. Helium used as a shielding gas produces greater penetration than argon, although argon produces a larger weld diameter. Gas flow should be set at approximately 6 cubic feet per hour (cfh).

Gas Tungsten Arc Spot Welding Procedure

To make a spot weld, the end of the welding gun is placed against the workpiece and the trigger is pulled. Squeezing the trigger starts the flow of cooling water and shielding gas and advances the electrode to touch the workpiece. As soon as the electrode touches the workpiece, it automatically retracts, establishing an arc. The arc is extinguished at the end of a preset length of time. The welding gun is usually preset at the factory to provide an arc length of $\frac{1}{16}''$, which is satisfactory for most welding applications.

The current required for welding is determined by the thickness of the metal to be welded. The major effect of increasing the current when both workpieces are approximately the same thickness is to increase penetration. However, it also tends to increase the weld diameter. Increasing the current when the bottom workpiece is considerably heavier than the top workpiece results in an increase in weld diameter with little or no increase in penetration. See Figure 28-11.

Manual gas tungsten arc spot welding can be performed using automatic sequencing controls to set the gas and water flow rates, control arc starting and intervals, and provide necessary postweld shielding gas and water flow.

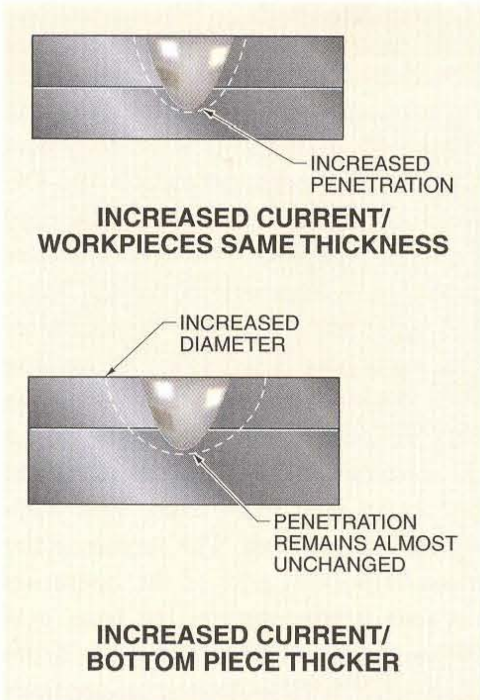


Figure 28-11. *The thickness of the workpieces being welded has an effect on weld diameter and penetration when the current is increased.*

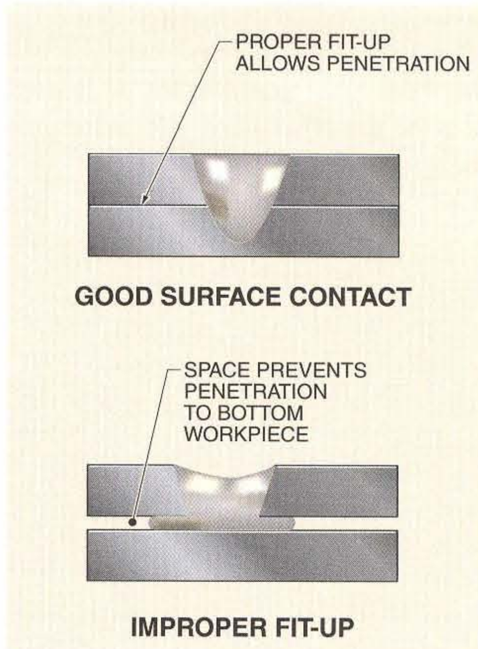


Figure 28-12. *Good surface contact is important to making a sound spot weld.*

Weld time is set on the dial of the control panel. The dial is calibrated in 60ths of a second and is adjustable from 0 sec to 6 sec. The effect of increasing the weld time is to increase the weld diameter. However, by increasing the weld diameter, penetration is also increased.

Mill scale, oil, grease, dirt, paint, and other foreign materials on or between the contacting surfaces prevent good contact and reduce weld strength. The space between the two contacting surfaces resulting from these surface conditions or poor fit-up acts as a barrier to heat transfer and prevents the weld from penetrating into the bottom workpiece. Consequently, good surface contact is important for sound welds. See Figure 28-12.

Stress relieving is used with GMAW to prevent distortion that occurs through localized heating. Stress relieving methods include electric resistance heating blankets, induction coils, and special furnaces.

Gas tungsten arc spot welding can be done from one side only so the bottom workpiece must have sufficient rigidity to permit the two workpieces to be brought into contact with pressure applied by the welding gun. If the thickness, size, or shape of the bottom workpiece is such that it does not provide enough rigidity, then some form of backing is required. Backing may be either steel or copper.

GAS METAL ARC WELDING IN PRODUCTION WELDING

GMAW is an economical and effective method of joining light-gauge, hard-to-weld metals such as nickel, stainless steel, aluminum, brass, copper, titanium, columbium, molybdenum, Inconel®, Monel®, and silver, as well as structural plates and beams. GMAW may be performed semiautomatically, mechanically, or automatically.

Semiautomatic GMAW uses welding equipment that controls only the filler metal feed. An operator controls the welding speed. When the trigger of the welding gun is pressed, the shielding gas, current, and filler metal

automatically begin to flow. See Figure 28-13. The operator simply keeps the weld concentrated in the designated area of the workpiece and maintains the proper travel speed.

Figure 28-13. *With a portable GMAW welding gun, the gas, current, and wire feed automatically begin to flow when the trigger is pressed.*

Miller Electric Manufacturing Company

Mechanized GMAW uses welding equipment that performs the welding operation under the constant observation and control of the operator. The welding head is stationary rather than portable. The welding head is either mounted on a carriage that travels over the workpiece or it is in a fixed position and the workpieces to be welded are moved beneath the unit.

Automatic GMAW uses welding equipment that performs the entire welding operation without constant observation and adjustment of the controls by the operator. The controls are set to the specified welding schedule and the machine performs the entire operation.

STUD WELDING

Stud welding is a form of electric arc welding. Stud welding is a term used for the process of joining a metal stud, or similar part, to a workpiece. Two methods of stud welding have been developed, the Nelson method and the Graham method, each with a different principle of operation.

Nelson Method

The Nelson method uses a flux and a ceramic guide or ferrule. Welding equipment consists of a welding gun, a timing device that controls the DC welding current, specially designed studs, and ceramic ferrules. Studs are available in a variety of shapes, sizes, and types to meet many applications. The studs have a recess in the welding end, which contains the flux. The flux acts as an arc stabilizer and a deoxidizing agent. An individual porcelain ferrule is used with each stud when welding. The ferrule is the most important part of the operation because it concentrates the heat, acts (with the flux) to prevent air from contacting the molten metal, confines the molten metal to the weld area, shields the glare of the arc, and prevents charring of the workpiece through which the stud is being welded.

A stud is loaded into the chuck of the welding gun and a ferrule is positioned over the stud. When the trigger is depressed, the current energizes a solenoid coil, which lifts the stud away from the workpiece, causing an arc that melts the end of the stud and the area on the workpiece. A timing device shuts the current OFF at the proper time. The solenoid releases the stud, a spring action plunges the stud into the weld pool, and the weld is made. See Figure 28-14.

Graham Method

The Graham method uses a small cylindrical tip on the joining face of the stud. The diameter and length of the tip vary with the diameter of the stud and the workpiece. The Graham method operates on AC current and requires an air source that can supply about 85 lb of air pressure.

The welding gun is air-operated with a collet (to hold the stud) attached to the end of a piston rod. Constant air pressure holds the stud away from the

Nelson Stud Welding Method
Figure 28-14

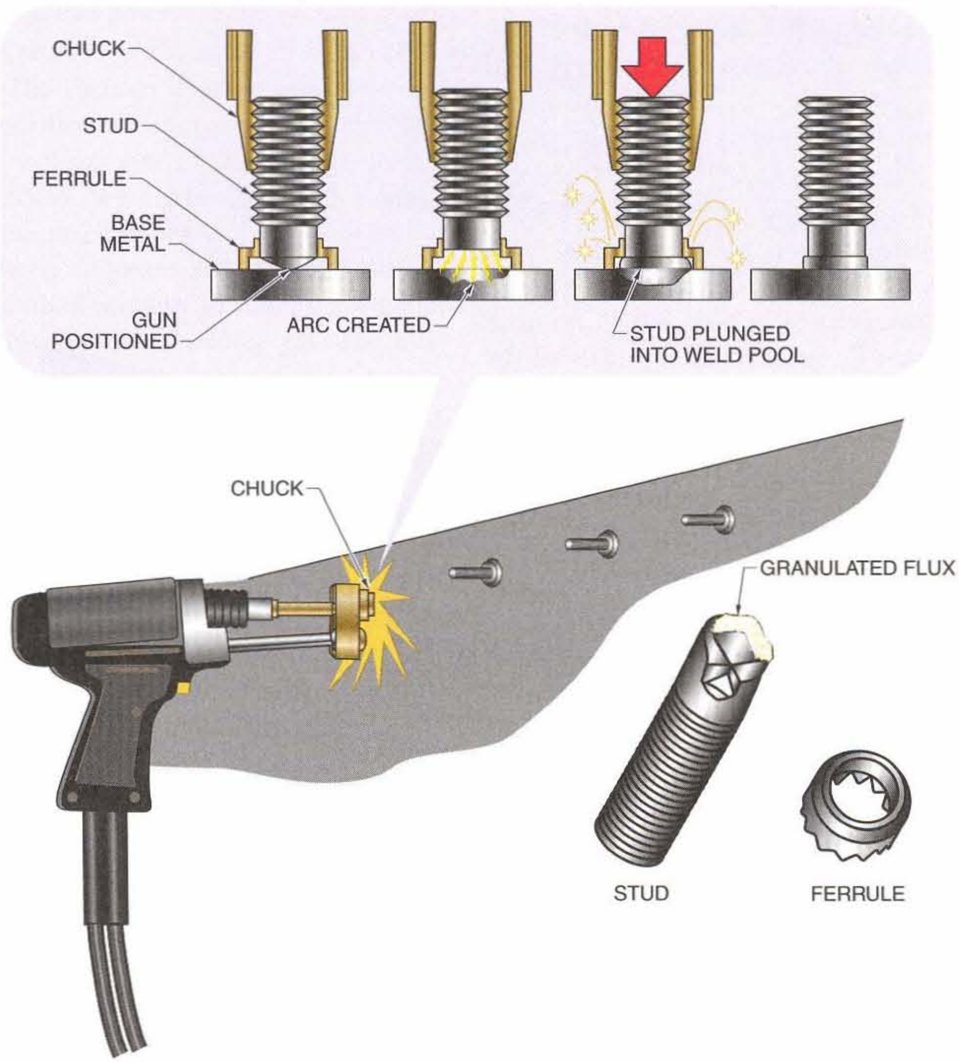


Figure 28-14. *A stud is loaded into the chuck of the gun and a ferrule is positioned over the stud. As the stud contacts the workpiece, an arc is started that melts the end of the stud and an area on the workpiece to which the stud is welded.*

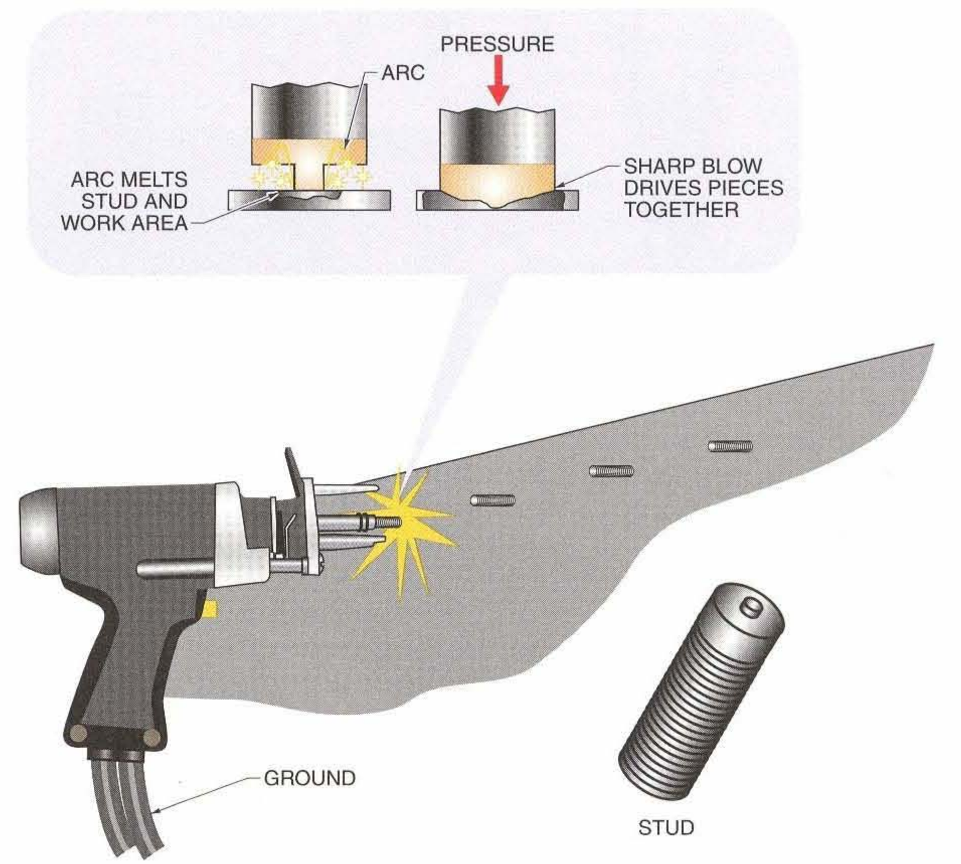
workpiece until it is sufficiently heated; then air pressure drives the stud against the workpiece. When the small tip touches the workpiece, a high-current, low-voltage discharge results, creating an arc that melts the entire area of the stud and the corresponding area of the work. Arcing time is about one millisecond (.001 sec); thus a weld is completed with little heat penetration, no distortion, and practically no fillet. The stud is driven at a velocity of about 31″ per second and the explosive action as it meets the workpiece cleans the area to be welded. A minimum workpiece thickness of .02″ is preferred, particularly if no marking on the reverse side is required. See Figure 28-15.

Both methods of stud welding are adaptable for welding most ferrous and nonferrous metals, their alloys, or any combination of them.

In stud welding, ferrules must be positioned exactly as required. Locating fixtures and equipment are used to accurately place ferrules in the proper location. A template can locate a ferrule to within ± 1/32″ of the specified location. A spacer on the template ensures accurate spacing between ferrules.

Figure 28-15. *On contact, ionization takes place, cleaning both surfaces. An arc results that melts the full diameter of the stud and a corresponding area of the workpiece. A sharp blow drives the two together, completing the weld.*

Graham Stud Welding Method
Figure 28-15



EBW is a fusion process where a high-power-density beam of electrons is focused on the area to be joined.

ELECTRON BEAM WELDING

Electron beam welding (EBW) is a welding process that produces coalescence with a concentrated beam, composed primarily of high-velocity electrons, impinging on the joint. EBW is performed without shielding gas and without exerting pressure on the weld. EBW is essentially a fusion welding process. Fusion is achieved by focusing a high-power-density beam of electrons on the area to be joined. Upon striking the metal, the kinetic energy of the high-velocity electrons changes to thermal energy, causing the workpiece to melt and fuse.

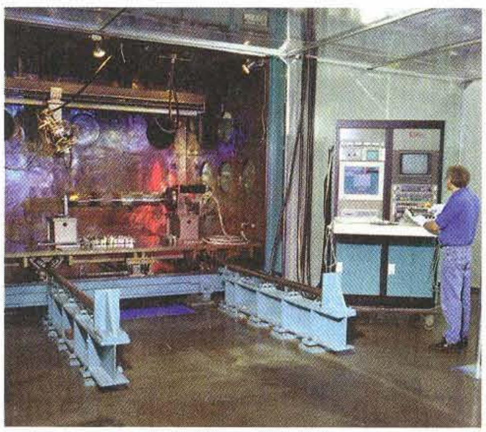
Electrons are emitted from a tungsten filament heated to approximately 3630°F (2000°C). Since the filament would quickly oxidize at this temperature if it were exposed to normal atmosphere, welding must be done in a vacuum chamber. Therefore, a vacuum chamber is necessary to prevent the electrons from colliding with molecules of air that would make the electrons scatter and lose their kinetic energy.

EBW can be used to join metals that range from thin foil to 2″ thick. It is particularly adaptable for welding refractory metals such as tungsten, molybdenum, columbium, and tantalum, and metals that oxidize readily, such as titanium, beryllium, and zirconium. It can also be used to join dissimilar metals, aluminum, standard steels, and ceramics.

EBW Processes

Electron beam welding is done using either of two processes: the vacuum chamber process or the beam-in-air process.

The vacuum chamber process uses a controlled vacuum environment where the welding gun and the workpieces are enclosed. See Figure 28-16. Because the vacuum chamber is free from atmospheric contaminants, the vacuum chamber process produces a cleaner weld without a shielding gas. The weld is more precise because the beam is much narrower in the vacuum chamber.



Sciaky, Inc.

Figure 28-16. *The welding gun and workpieces are enclosed in the vacuum chamber of an electron beam welding machine.*

The beam-in-air process uses a gun that has a vacuum chamber that surrounds the area where electrons exit from the welding gun; welding is done in the open atmosphere. To shield the weld area from atmospheric contaminants, argon is used as a shielding gas. The welds produced by the beam-in-air process are similar to welds made using GTAW.

EBW has several advantages over other processes. It welds with a low total-energy input. Workpiece distortion and effects on the properties of the workpiece are reduced. The weld size and location can be controlled relative to the energy input, but it is relatively narrow. EBW is chemically clean and facilitates welding without contamination of the work-piece. Using the beam-in-air process allows greater welding speed than GTAW.

EBW is often associated with the joining of difficult-to-weld metals. It is used in aerospace fabrication where new metals require more exacting joining characteristics; however, adaptation of the process to commercial applications is increasing. There is every indication that this growth will continue.

One of the major limitations of EBW using the vacuum chamber process is that the piece must be small enough to fit into the vacuum chamber. This limitation is being reduced to some extent because large chambers are now manufactured to accommodate a variety of product sizes. Another limitation is that when the workpiece is in the chamber in a vacuum it becomes inaccessible. It must be manipulated using special controls.

EBW Equipment

An electron gun consists of a filament, cathode, anode, and focusing coil. The electrons emitted from the heated filament carry a negative charge and are repelled by the cathode and attracted by the anode. The electrons pass through the anode and then through a magnetic field generated by the electromagnetic focusing coil. An optical viewing or numerical control system determines the path of the electron beam centerline to the weld area. See Figure 28-17.

By varying the current to the focusing coil, the operator can focus the beam for gun-to-work distances ranging from ½″ to 25″. The electron beam can be controlled with a focusing coil to produce a spot diameter of less than .005″.

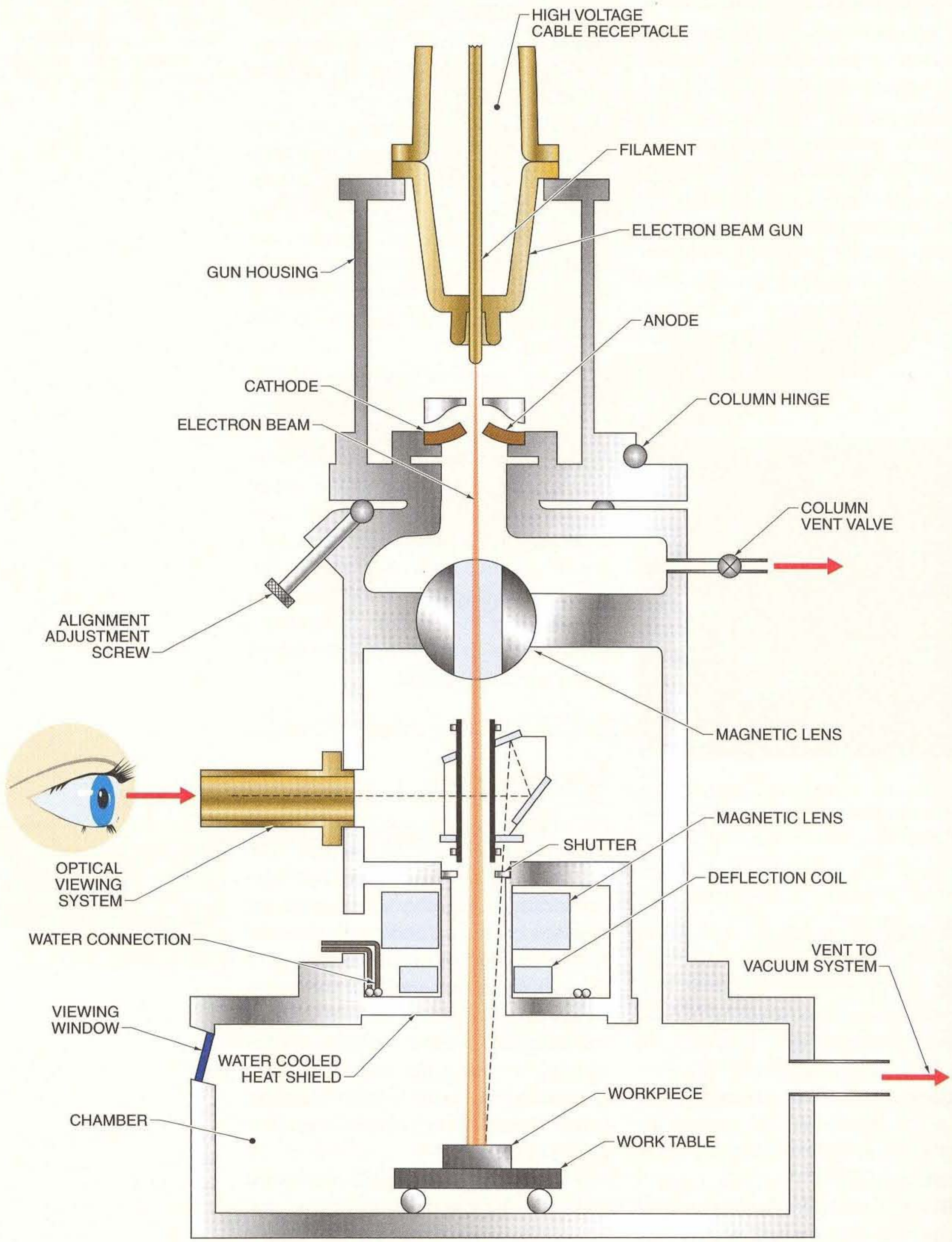


Figure 28-17. *In the electron beam column, the electrons pass through an aperture in the anode and then through a magnetic field generated by the electromagnetic focusing coil. An optical viewing system provides a line of sight down the path of the electron beam centerline to the weld area.*

A vacuum chamber has heavy glass windows to permit viewing the work. A work table in the chamber is arranged so it can be operated either manually or electrically along the x- and y-axes. T-slots are provided on the table to attach fixtures or workpieces for welding.

A vacuum pumping system is designed to clean and dry the vacuum chamber in a relatively short time. The capacity of the pump required is determined by the volume and area of the vacuum chamber and the time required to evacuate the chamber. The pumping equipment is usually completely automatic once setup is completed.

Necessary electrical controls include setup controls and operating controls. Setup controls include instruments required for the initial setup of the welding operation, such as meters for beam voltage, beam current, focusing current, and filament current. Operating controls consist of stop-and-start sequence, high-voltage adjustment, focusing adjustment, filament activation, and work table motion.

EBW Procedure

The workpiece is positioned on the work carriage in the vacuum chamber. The electron gun and the work-to-gun distance are aligned manually and visually using the optical system. Work travel or welding gun travel, depending on the type of welding facility used, is aligned. The vacuum chamber is then closed. Vacuum controls are started and the chamber is pumped down to the required vacuum, which is prescribed in the weld schedule.

Beam voltage, beam current, filament current, and focusing current controls are set based on the weld schedule. The weld schedule is usually determined by a welding engineer. Once the control settings have been checked, the beam current is switched ON for an instant and OFF again for a weld spot alignment check. The weld or weld area is viewed by opening the shutter only when the beam current is turned OFF. If the shutter is opened when the beam current is ON, the optical system can be severely damaged.

After all controls and settings have been checked and all switching made operative, welding is begun by turning the sequence start switch to the ON position. The weld is made automatically.

FRICTION WELDING

In FRW, heat resulting from the parts being rotated together is used to fuse the pieces.

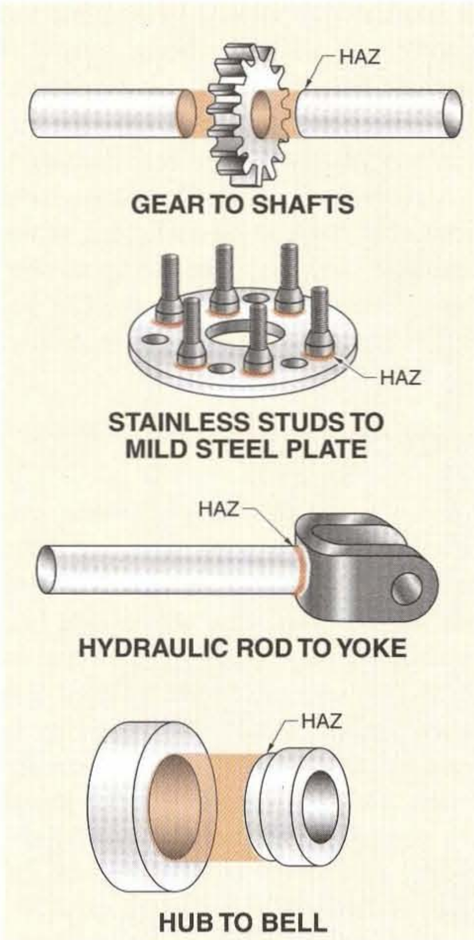
Friction welding (FRW) is a welding process that joins two metal parts that rotate or are in relative motion with respect to one another when they are brought into contact and pressure is applied between them. Friction, or inertia, welding is a process where stored kinetic energy is used to generate the required heat for fusion. The two workpieces to be joined are aligned end to end. One is held stationary by a chuck or a fixture, and the other is clamped in a rotating spindle.

The rotating workpiece is brought up to a certain speed to develop sufficient energy. The drive source is disconnected and the pieces are brought into contact under a computed thrust load. At this point, the kinetic energy contained in the rotating mass converts to frictional heat. The metal at and immediately behind the interface is softened, permitting fusion to take place between the workpieces.

FRW has several advantages over conventional FW or UW. It produces improved welds at higher speed and lower cost, less electrical current is required, and costly copper fixtures are eliminated. With FRW there is less shortening of the components, which often occurs with FW or UW. Additionally, the HAZ near the weld is confined to a very narrow band. See Figure 28-18.

FRW can be used to weld dissimilar as well as similar metals. Weld strength is normally equal to that of the original metals.

Figure 28-18. *On friction-welded workpieces, the HAZ is confined to a very narrow band.*



LASER BEAM WELDING

Laser beam welding (LBW) is a welding process that produces coalescence with the heat from a laser beam impinging on the joint. Laser beam welding is used without shielding gas and without exerting pressure on the weld. Fusion is achieved by directing a highly concentrated beam to a spot about the diameter of a human hair. The highly concentrated beam generates a power intensity of 1 billion or more watts per square centimeter at its point of focus. Because of its excellent heat input control, LBW can be used near glass or varnish-coated wires without damaging the glass or the insulating properties of the varnish.

Laser beam welding (LBW) is a welding process that produces coalescence with the heat from a laser beam impinging on the joint.

Since the heat input to the workpiece is extremely small in comparison to other welding processes, the size of the HAZ and the thermal damage to the adjacent parts of the weld are minimized. It is possible to weld heat-treated alloys without affecting their heat-treated condition, and the weld can be held in the hand immediately after welding is completed.

LBW can be used to join dissimilar metals such as copper, nickel, tungsten, aluminum, stainless steel, titanium, and columbium. Additionally, the laser beam can pass through transparent substances without affecting them, making it possible to weld metals that are sealed in glass or plastic. Because the heat source is a light beam, atmospheric contamination of the weld joint is not a problem.

LBW is used in the aerospace and electronic industries where extreme control of the weld is required. A major limitation of LBW is its shallow penetration.

The duration of the beam is usually about .002 sec, with a pulse rate of one to 10 pulses per second. As each point of the beam hits the workpiece, a spot is melted that resolidifies in microseconds. The weld line consists of a series of round, solid, overlapping weld pools. The workpiece is moved beneath the beam or the energy source is moved across the weld. The beam is focused onto the workpiece using an optical system and the welding energy is controlled by a switch.

Laser Beam Theory

Atoms have been made to give off energy by exciting them in such common devices as fluorescent lights and television tubes. *Fluorescence* is the ability of certain atoms to emit light when they are exposed to external radiation of shorter wavelengths.

In LBW, the atoms that are excited to produce the laser light beam are produced in a synthetic ruby rod ⅜″ in diameter. The ruby rod is identical to a natural ruby but has a more perfect crystalline structure. About .05% of its weight is chromium oxide. The chromium atoms give the

ruby its red color because they absorb green light from external light sources. When the atoms absorb this light energy, some of their electrons are excited. Thus, green light is said to pump the chromium atoms to a higher energy state.

The excited atoms eventually return to their original state. As they do, a portion of the extra energy they previously absorbed (as green light) is given off in the form of red fluorescent light. When the red light emitted by one excited atom hits another excited atom, the second atom gives off additional red light. The additional red light is in phase with the colliding red light wave, increasing the intensity of the light. In other words, the red light from the first atom is amplified because more red light exactly like it is produced.

By using a very intense green light to excite the chromium atoms in the ruby rod, a larger number of its atoms can be excited and the chances of collisions are increased. To further enhance this effect, the parallel ends and the sides of the rod are mirrored to bounce the red light back and forth within the rod. When a certain critical intensity of pumping is reached (the threshold energy), the chain reaction collisions become numerous enough to cause a burst of red light. The lens at the front end of the rod is only a partial reflector, allowing the burst of light to escape through it. See Figure 28-19.

PLASMA ARC WELDING

Plasma arc welding (PAW) is an arc welding process that uses a constricted arc between a nonconsumable tungsten electrode and the weld pool (transferred arc), or between the electrode and constricting nozzle (nontransferred arc).

The electrode and part are shielded by ionized gas (plasma) issuing from the torch, which may be supplemented by an auxiliary shielding gas. PAW uses a central plasma core of extreme temperature surrounded by a sheath of cool gas. See Figure 28-20. The required heat for fusion is generated by an electric arc that has been highly intensified by the injection of a gas into the arc stream. The superheated arc column is concentrated into a narrow stream, and when directed onto a workpiece, can make a groove weld ½″ thick or more in a single pass without filler metal or edge preparation.

PAW uses an electric arc that is highly intensified by the injection of gas into the arc stream, which results in a jet of high current density.

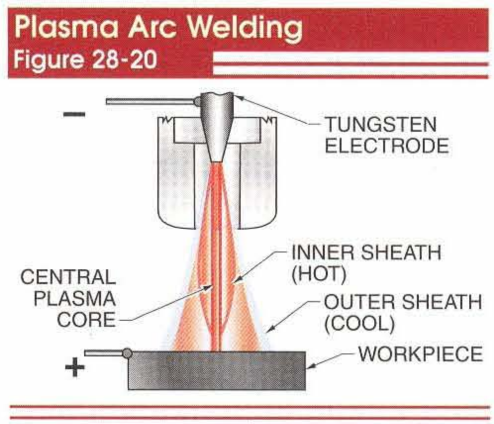


Figure 28-20. *PAW uses a central plasma core of extreme temperature surrounded by a sheath of cool gas.*

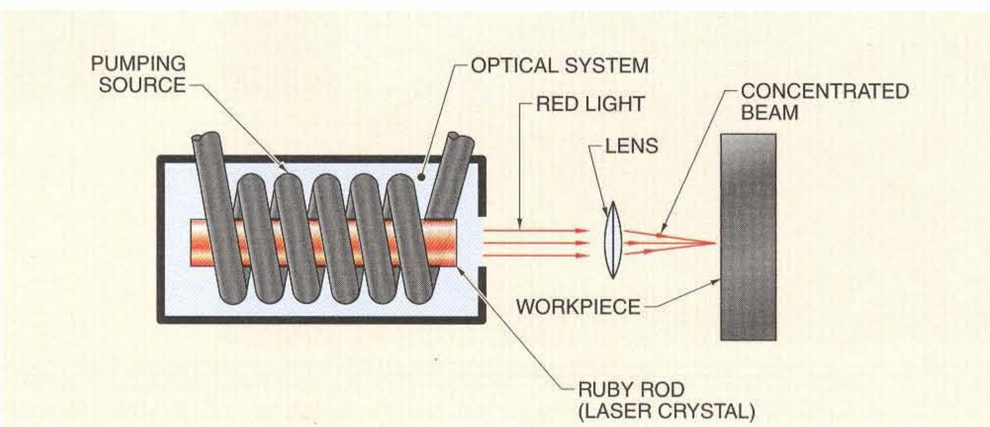


Figure 28-19. *The LBW machine has a concentrated beam that is focused on the workpiece with an optical system.*

In some respects, PAW may be considered an extension of GTAW. The main difference is that in PAW, the arc column is constricted. This constriction produces a much higher heat transfer rate.

The arc plasma actually becomes a jet of high current density. The plasma gas, upon striking the workpiece, cuts or keyholes, entirely through the workpiece, producing a small hole that is carried along the weld. During this cutting action, the melted metal in front of the arc flows around the arc column, then is drawn together immediately behind the hole by surface tension forces, reforming in a weld bead.

Plasma arc welding can be used to weld stainless steels, carbon steels, Monel®, Inconel®, titanium, aluminum, copper, and brass alloys. Filler metal is typically not needed; however, a continuous filler wire can be added.

PAW Equipment

A regular heavy-duty DC rectifier is used as the power source for PAW. A special control console is required to provide the necessary operating controls. A water-cooling pump is usually needed to ensure a controlled flow of cooling water to the torch at a regulated pressure. Proper cooling prolongs the life of the electrode and the nozzle. See Figure 28-21.

PAW Circuit
Figure 28-21

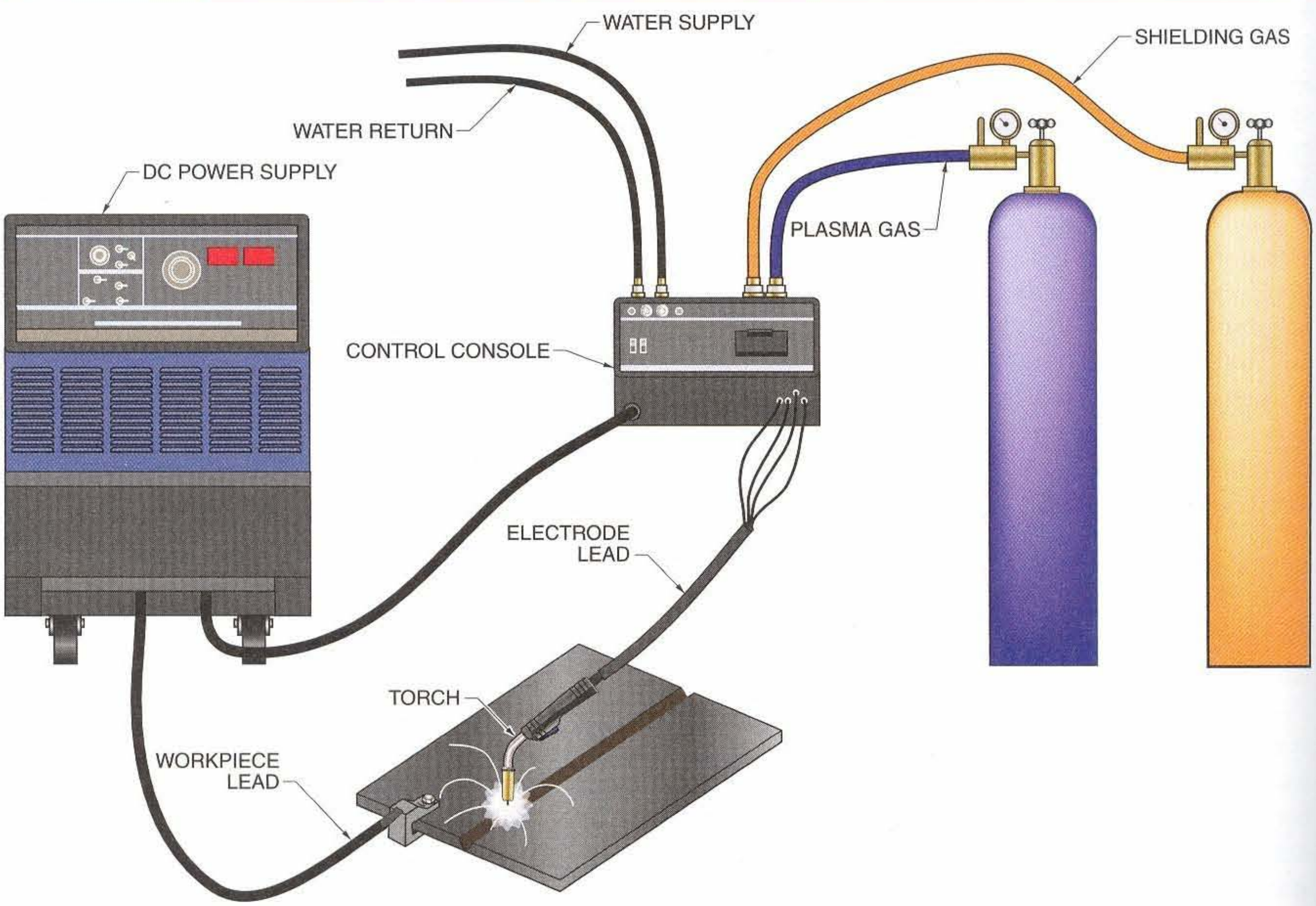
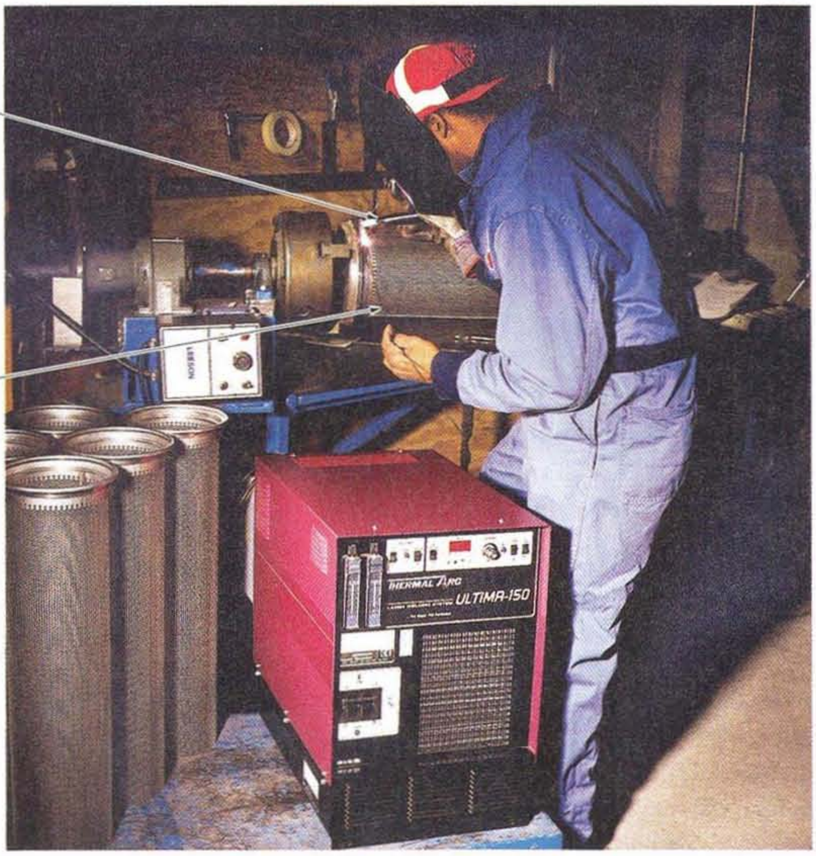


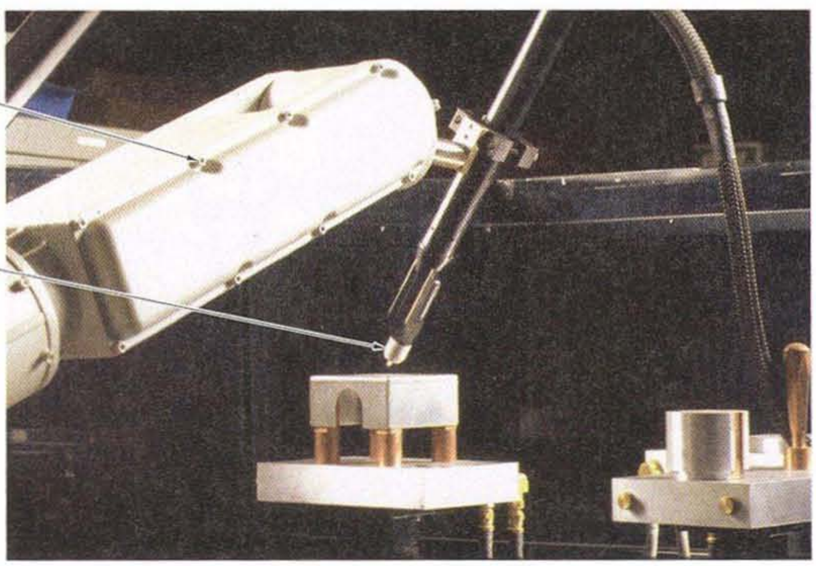
Figure 28-21. *The PAW welding circuit includes a DC power source, control console, water supply, plasma gas and shielding gas supply, welding cables, and torch.*

Torches specially designed for PAW can be hand-held or mounted for stationary or mechanized applications. See Figure 28-22. The shielding gas supply should be either argon or helium. In some applications, argon is used as the plasma gas and helium as the shielding gas. However, in many operations argon is used for both shielding and generating the plasma arc.

PAW Torches
Figure 28-22



HAND-HELD



MOUNTED

Thermal Arc, a division of Thermadyne Industries, Inc.

Figure 28-22. *Torches specially designed for PAW can be hand-held or mounted for stationary or mechanized applications.*

SUBMERGED ARC WELDING

In SAW, the electric arc is completely hidden beneath a flux.

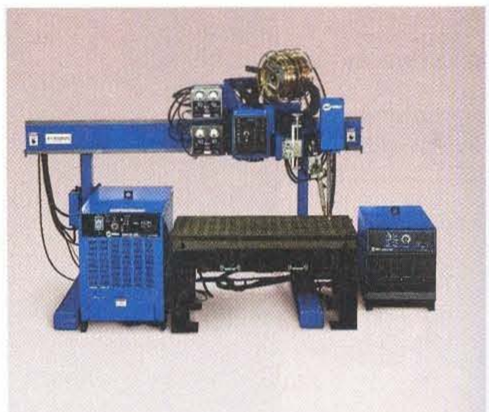
No inert shielding gas is required for SAW since the flux completely surrounds the electric arc.

Submerged arc welding (SAW) is an arc welding process that uses an arc between a bare metal electrode and the weld pool. A blanket of granular flux, supplied from the electrode, forms a layer of slag that protects and shields the arc and weld pool from contamination. The granulated flux shields the welding action and covers the molten metal. The weld is submerged beneath the flux and slag. Pressure is not used on the weld during SAW. See Figure 28-23.

SAW can be either semiautomatic or automatic. The welding unit used with the automatic process is set up to move over the weld area at a controlled speed. See Figure 28-24. On some machines, the welding head moves and the work remains stationary. In others, the head is stationary and the work moves. Semiautomatic SAW requires the use of a special welding gun.

SAW can be used for metals from 1/16″ thick. It is usually used for welding thick metals and where deep penetration is required. For example, it is possible to weld 3″ plate in a single pass. However, caution is necessary as impurities in the weld collect toward the center of the weld, developing a weak area. Very little edge preparation is necessary on metal less than ½″ thick. Generally, backing is essential when welding thick steel. Welding positions are limited because of the large amount of fluid molten metal.

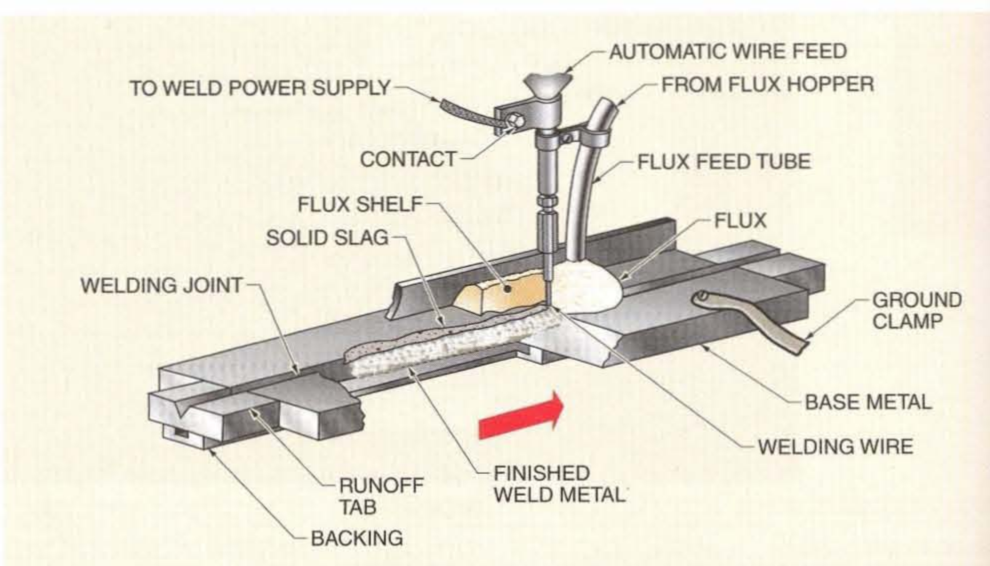
The difference between SAW and GMAW is that no inert shielding gas is required. The welding gun is pointed over the weld area and the trigger is pressed. As soon as the trigger is pressed, the welding wire is energized and the arc is started. At the same time, flux begins to flow. Welding is then carried out in the same manner as GMAW.



Miller Electric Manufacturing Company

Figure 28-24. *The welding unit used with the automatic process is set up to move over the weld area at a controlled speed.*

Figure 28-23. *A cutaway view of an SAW machine shows how the granulated flux shields the welding action and covers the molten metal.*



SAW Equipment

The welding equipment required for SAW includes a power source, wire feed and drive assembly, welding gun, and flux delivery system. Any regular GMAW DC welding machine can be adapted for SAW. Since SAW is usually automated, the power source must be capable of an output and a duty cycle that can match the operation being performed. The metal thickness dictates the required current. Light-gauge metal requires as little as 300 A, while thick metals may require 1000 A or more.

A constant-voltage power source sets the voltage and holds it relatively constant. Current is determined by the feed speed of the electrode wire. As the wire feed speed is increased, more current is required to burn off the wire. Conversely, when the wire feed speed is decreased, less current is required.

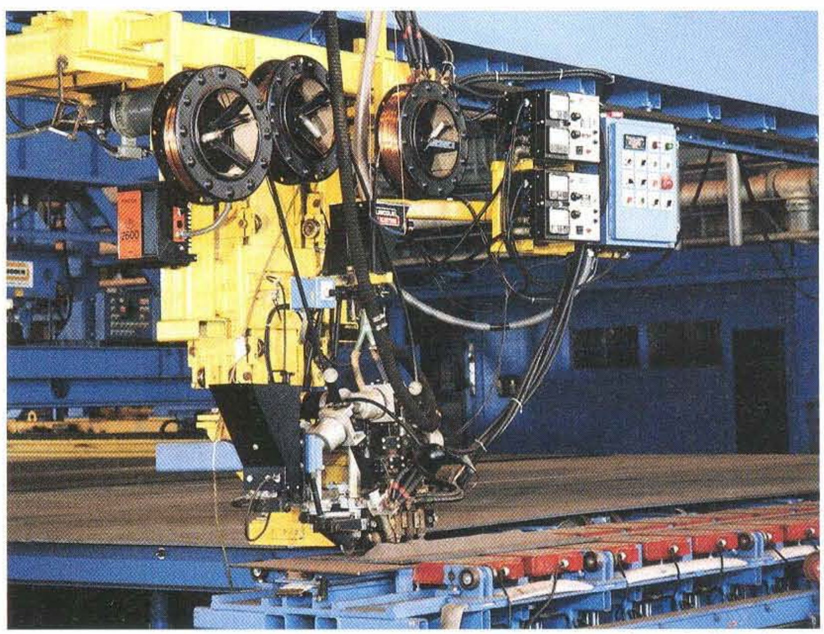
With a constant-current power source, a voltage-sensing wire feeder may be used. A voltage-sensing wire feeder increases the speed of the wire feed motor when the arc voltage increases and reduces the speed of the wire feed motor when the voltage decreases, maintaining a fairly constant arc voltage and length. However, it does not provide a consistent deposition rate.

Wire feed systems used for GMAW or FCAW can be used for SAW, provided they can feed the required wire size at the proper speed. For semiautomatic SAW, a standard wire feeder is normally used. When using a constant-current power source, special wire feeders that change feed rates in response to arc voltage changes are sometimes used. Burnback controls may be used for both semiautomatic and automatic SAW to prevent the electrode wire from sticking to the weld pool at the end of the weld.

The welding wire should be clipped to a sharp point as close to the flux cone as possible. Once the voltage and current are set, the welding gun is positioned over the joint. As the welding wire is fed into the weld zone, the welding gun deposits the granulated flux over the weld pool and completely shields the welding action. The arc is not visible since it is buried in the flux, thus there is no flash or spatter. The portion of the granular flux immediately around the arc fuses and covers the molten metal, but after it has solidified, it can be tapped off easily with a chipping hammer.

Flux can be delivered to the weld pool by either the gravity feed or forced-air feed method. The gravity feed method is designed for short-duration welds that are easily accessible. It is limited by the amount of flux that the operator can handle in the flux canister.

The forced-air flux feeding method is commonly used for semiautomatic welding. A conventional wire-feeding unit feeds the welding wire to the weld pool. A pressurized storage tank that holds approximately 100 lb of flux and a hand-held welding gun with a high-pressure air feed attachment are also used. An air supply is attached to the flux storage tank. The tank's regulator adjusts the pressure that feeds the flux through the tubing to the welding gun and the weld pool.



The Lincoln Electric Company

An automatic submerged arc welding machine is designed to move over the weld area while depositing the weld in flat position.

USW is a process where vibratory energy disperses the moisture, oxide, and surface irregularities between the pieces, thereby bringing the surfaces into close contact to form a permanent bond.

ULTRASONIC WELDING

Ultrasonic welding (USW) is a welding process that produces a weld by applying high-frequency vibratory energy to workpieces that are held together under pressure. Theoretically, if two workpieces with perfectly smooth surfaces are brought into close contact, the metal atoms of one workpiece will unite with the atoms of the other piece to form a permanent bond. However, regardless of how smooth such surfaces are a sound metallic bond normally does not occur because it is impossible to prepare surfaces that are absolutely smooth.

Whatever method is used to smooth surfaces, they still possess peaks and valleys (as seen by a microscope). As a result, only the peaks of the workpieces that come into close contact unite, producing no bond in the valleys. Also, smooth surfaces are never completely clean. Oxygen molecules from the atmosphere react with the metal to form oxides. These oxides attract water vapor, forming a film of moisture on the oxidized metal surface. Both the moisture and oxide film also act as barriers to prevent close contact.

In USW, to overcome the barriers to fusion, the interface between the workpieces is plastically deformed. This is done by means of vibratory energy, which disperses moisture and oxide and levels an irregular surface to bring the surfaces of both workpieces into close contact and form a solid bond. Vibratory energy is generated by a transducer. See Figure 28-25.

USW Equipment

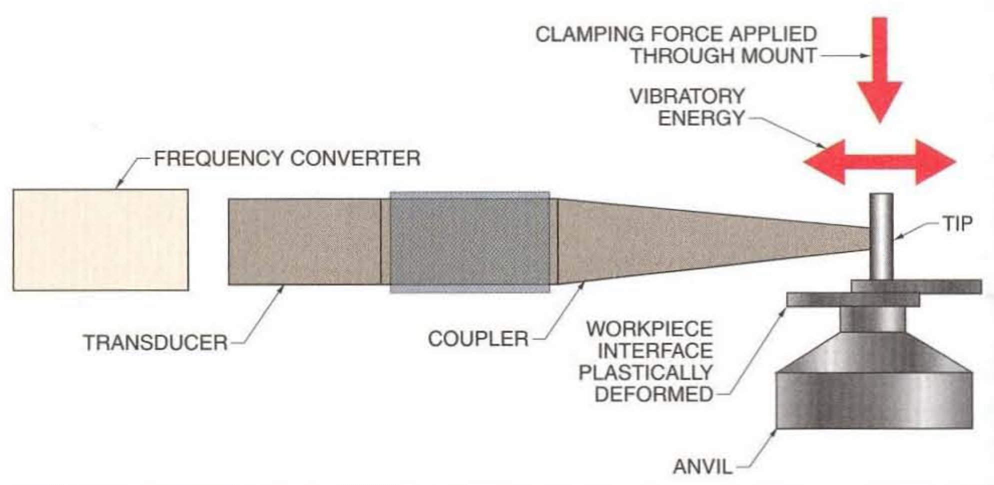
The welding equipment used for USW consists of two units: a power source or frequency converter, which converts 60 Hz line power into high-frequency electrical power; and a transducer. The components to be joined are simply clamped between a welding tip and supporting anvil with just enough pressure to hold them in close contact.

USW Procedure

High-frequency vibratory energy is transmitted to the joint for a required period. Bonding is accomplished without applying external heat or adding filler metal. Welding variables such as power, clamping force, weld

Figure 28-25. *An ultrasonic continuous-seam welder is often used for complete sealing of components used in electronics.*

Ultrasonic Welding
Figure 28-25



time for spot welds or welding rate for continuous-seam welds can be preset and the cycle completed automatically. A switch lowers the welding head, applies the clamping force, and starts the flow of ultrasonic energy.

Successful USW depends on the proper relationship between welding variables, which is usually determined experimentally for each application. Clamping force may vary from a few grams for very thin metals to several thousand pounds for thick metals. Weld time may range from .005 sec to 1 sec for spot welding and a few feet per minute (fpm) to 400 fpm for continuous-seam welding. The high-frequency electrical input to the transducer may vary from a fraction of a watt to several kilowatts.

USW is particularly adaptable for joining electrical and electronic components, hermetic sealing of materials and devices, splicing metallic foil, welding aluminum wire and sheet, and fabricating nuclear fuel elements. Spot welds or continuous-seam welds can be made on a variety of metals ranging in thickness from .00017″ (aluminum foil) to .10″. Thick sheet and plate can be welded if the machine is specifically designed for them. High-strength bonds are possible on similar and dissimilar metal combinations.

ELECTROGAS WELDING

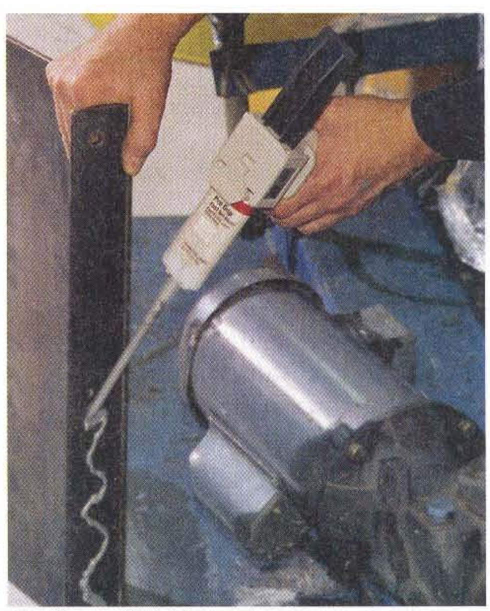
Electrogas welding (EGW) is a welding process that uses an arc between a filler metal electrode and the weld pool, using approximately vertical welding and a backing bar to control the weld metal. EGW can be used with or without shielding gas and without exerting pressure on the weld. EGW uses a gas-shielded metal arc and is designed for single-pass welding of vertical joints on steel ranging in thickness from 3/8″ to 1½″.

The welding head is suspended from an elevator mechanism that provides automatic control of the vertical travel speed during welding. This mechanism raises the welding head automatically at the same rate as the advancing weld metal. The welding head is self-aligning and can follow any alignment irregularity in the metal or in the joint.

Once the equipment is positioned on the joint, welding is completely automatic. The wire feed speed and the current levels remain constant. At the end of the weld, the process stops automatically. The EGW technique is especially adaptable for shipbuilding and fabrication of storage tanks and large-diameter pipes.

ADHESIVE BONDING

Adhesive bonding (AB) is used to join parts with an adhesive placed between the faying (mating) surfaces. AB is useful for joining dissimilar metals, plastics, and composites in manufacturing and repair operations. AB can be used to reduce the number of fasteners required and to strengthen joints prone to failure from vibration. See Figure 28-26.



Fel-Pro Chemical Products

Figure 28-26. *Adhesive bonding is used to join dissimilar materials and strengthen joints prone to failure from vibration.*

Thin metals subject to heat distortion can be joined with adhesives. For example, auto body panels joined with adhesives do not have depressions caused by resistance welding heat. Workpiece joint dimensions do not affect bonding strength.

Thin metals can be joined with thick metals. Adhesives fill the voids between workpieces without breaking surface contours. The flexibility of adhesives also allows distortion without failure. Joint types for AB require large contact areas for adhesion, as in brazing and soldering.

AB requires proper surface preparation, application, and curing procedures. The faying surfaces must be clean and free of foreign matter. Adhesives are selected by the material and application of the parts to be joined. See Figure 28-27. Adhesive application processes can be manual, semiautomatic, mechanized, automatic, and robotic, depending on the equipment available. Equipment required for adhesive bonding varies depending on application and curing methods. Adhesives are cured by chemical action using catalyst cure (two parts), evaporation, ultraviolet (UV) light, heat, pressure, or both heat and pressure.

Adhesives are available in various viscosities. *Viscosity* is the resistance of a substance to flow in a fluid or semi-fluid state. Low-viscosity adhesives are liquid in form, and flow readily into small spaces. High-viscosity adhesives range from gels to plastic-like forms. In some applications, an adhesive functions as a sealant. A *sealant* is a product used to seal, fill voids, and waterproof parts. Adhesive selection is based on the material and application of the parts to be joined.

Adhesive Types

Adhesives can be broadly classified by chemical content or base as acrylic, anaerobic, cyanoacrylate, epoxy, hot melt, polyurethane, polysulfide, silicone, solvent-base, or water-base adhesives.

ADHESIVE BONDING

Adhesive	Components	Cure Time	Viscosity	Void-Filling	Flexibility	Heat Resistance	Cold Resistance	Thermal Resistance	Water Resistance	Metal Bonding
Acrylic	Two-part One-part (UV or Heat cure)	Medium to Fast	Medium	Good	Good	Good	Good	Good	Good	Good
Anaerobic	One-part	Medium	Low	Poor to Fair	Good	Good	Good	Good	Good	Fair
Cyanoacrylate	One-part	Fast	Low	Poor to Fair	Poor to Fair	Fair	Fair	Good	Fair	Good
Epoxy	Two-part One-part (heat cure)	Slow to Medium	Medium to High	Excellent	Fair	Good	Fair	Good	Good	Good
Hot Melt	One-part	Fast	High	Excellent	Fair to Good	Poor to Fair	Fair	Fair	Good	Fair
Polyurethane	One-part Two-part	Medium	Medium	Good	Good	Fair	Good	Good	Fair	Good
Polysulfide	One-part Two-part	Medium	High	Excellent	Good	Good	Good	Excellent	Good	Good
Silicone	One-part Two-part	Medium	High	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Fair
Solvent-base	One-part	Medium	Low to Medium	Poor to Fair	Good	Good	Good	Good	Good	Good
Water-base	One-part	Medium	Low to Medium	Poor to Fair	Poor to Fair	Fair	Fair	Poor	Poor	Poor to Fair

Figure 28-27. *Adhesives are selected based on the material and application of the parts to be joined.*

An *acrylic* is a one-part UV (heat cure), or a two-part adhesive that can be used on a variety of materials. It has a fast setting time and excellent flexibility. An *anaerobic adhesive* is a one-part adhesive or sealant that cures due to the absence of air which has been displaced between mated parts. Low-viscosity anaerobic adhesives are commonly used for locking metal parts together such as screws, nuts, and other fasteners. High-viscosity anaerobic adhesives are used for joining parts that have large gaps between faying surfaces.

A *cyanoacrylate adhesive* is a one-part adhesive that cures instantly by reacting to trace surface moisture to bond mated parts. Cyanoacrylate adhesives have common names such as instant glue or super glue and have a low resistance to high temperatures, moisture, vibration, and shock. *Epoxy* is a two-part adhesive that cures when resin and hardener are combined. Some epoxies are heat-cured.

A *hot melt adhesive* is thermoplastic material that is applied in a molten state and cures to a solid state when cooled. A hot melt adhesive is not as strong as epoxy but is very fast setting. *Polyurethane* is a one- or two-part adhesive with excellent flexibility that cures by evaporation, catalyst, or heat. A *polysulfide adhesive* is a one- or two-part adhesive or sealant that cures by evaporation or catalyst. It is commonly used in the aerospace and building materials industry.

Silicone is a one- or two-part adhesive or sealant that cures by evaporation or catalyst. It has high temperature resistance and excellent sealing characteristics. A *solvent-base adhesive* is a one-part adhesive with a rubber or plastic base that cures by solvent evaporation. It is commonly used as contact cement for bonding large surface areas and lamination applications. A *water-base adhesive* is a one-part adhesive that cures by water evaporation. A water-base adhesive is low in flexibility and is primarily used for wood and paper products.

OTHER WELDING PROCESSES

Other welding processes approved by the AWS may be used for particular applications. These processes include explosion welding, forge welding, roll welding, and cold welding.

Explosion Welding

Explosion welding (EXW) is a welding process that produces a weld by extreme impact of the metals through controlled detonation. Coalescence occurs from the explosive force of the impact on the heated surface. EXW forms a strong bond between many metals, including dissimilar metals that cannot be joined by arc welding. EXW is commonly used for cladding steel with thinner metals.

Forge Welding

Forge welding (FOW) is a welding process that produces a weld by heating the metals to welding temperature and applying forceful blows to cause deformation at the faying surfaces. FOW is one of the oldest welding procedures, commonly used by blacksmiths for joining metals. The metals are heated to a red-hot temperature and a hammer and anvil are used to deform the surface. Flux is often applied to aid in bonding the joint.

Roll Welding

Roll welding (ROW) produces a weld by applying heat and pressure using rollers to cause deformation at the faying surfaces. ROW is similar to forge welding except that the weld is formed by rollers rather than a hammer. ROW is commonly used for welding pipe and for cladding mild- or low-alloy steel with high-alloy steel.

Cold Welding

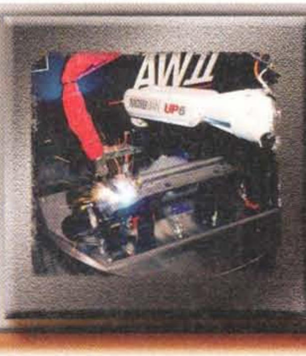
Cold welding (CW) is a welding process in which a weld is produced using pressure at room temperature to cause deformation at the joint. Coalescence occurs because of the pressure that is applied. Surface oxides and contaminants must be removed before CW takes place. Power brushing is the best method to clean the surface. Many soft metals that cannot be welded, as well as many dissimilar metals such as aluminum and copper or iron and copper, can be joined using CW.

POINTS TO REMEMBER

1. Spot welding is a form of RW with wide application in industry.
2. Spotwelders are available to produce single spot welds or multiple spot welds.
3. Seam welding produces a series of overlapping spot welds, thereby making a continuous-weld seam.
4. In multiple-impulse welding, the current is regulated to go on and off a number of times during the welding process.
5. When gas tungsten arc spot welding, set the current based on the thickness of the metal to be spot welded.
6. EBW is a fusion process where a high-power-density beam of electrons is focused on the area to be joined.
7. In FRW, heat resulting from the parts being rotated together is used to fuse the pieces.
8. Laser beam welding (LBW) is a welding process that produces coalescence with the heat from a laser beam impinging on the joint
9. PAW uses an electric arc that is highly intensified by the injection of gas into the arc stream, which results in a jet of high current density.
10. In SAW, the electric arc is completely hidden beneath a flux.
11. No inert shielding gas is required for SAW since the flux completely surrounds the electric arc.
12. USW is a process where vibratory energy disperses the moisture, oxide, and surface irregularities between the workpieces, thereby bringing the surfaces into close contact to form a permanent bond.

QUESTIONS FOR STUDY AND DISCUSSION

1. What is the basic principle of resistance welding?
2. What is projection welding?
3. What is meant by multiple-impulse welding?
4. How does upset welding differ from flash welding?
5. What is the advantage of gas tungsten arc spot welding over conventional resistance spot welding?
6. What are some advantages and limitations of electron beam welding?
7. What is the principle of friction welding?
8. In laser beam welding, how is the high-intensity laser light beam generated?
9. How does PAW differ from regular GTAW?
10. What is SAW and what are some of its advantages?
11. How is fusion of metal accomplished in ultrasonic welding?
12. What are some advantages of adhesive bonding?



Automation & Robotic Welding 29

Other Welding Processes

Automation in production welding offers greater efficiency and weld quality control to manufacturers and fabricators. Automation requires that some or all of the steps of an operation be performed in sequence by electronic or mechanical means. Many welding processes can be automated for production welding that requires consistent, rapidly repeated welds. Automatic welding is most commonly used in automation systems. Automation in production welding can be broadly classified as fixed automation and flexible automation. Fixed automation uses mechanically directed movements of the torch and workpiece. Flexible automation uses programmable movements of a robotic torch and the workpiece. Automated welding equipment is used to achieve the accuracy and speed needed in a production environment.

AUTOMATION IN PRODUCTION WELDING

Automation in production welding offers greater efficiency and weld quality control to manufacturers and fabricators. Production welding processes have evolved as new welding technology has been developed. Production welding processes used for automation in welding are mechanized, semiautomatic, and automatic welding processes. Automatic welding is most commonly used in automation systems. Automation in production welding can be broadly classified as fixed automation and flexible automation.

Fixed Automation Systems

A *fixed automation system* is a system that uses machines designed for a specific production function. Fixed automation systems are primarily used for simple production path welds such as circles, linear seams, or radial seams. A fixed automation system is generally used in production facilities demanding high volume and repeated welds.

Fixed automation equipment uses mechanical and electrical means to guide the torch and the workpiece. Fixed automation equipment provides more arc-on time, better accuracy and speed, and lower cost than manual welding processes. The torch may be fixed and the workpiece moved about the torch, such as on a pipe weld; or the workpiece may be fixed and the torch moved, such as on a seamer. See Figure 29-1.

Pandjiris, Inc.

Figure 29-1. *Fixed automation equipment is designed for a specific production function.*

Since the welding equipment is mechanical, the operator must adjust the mechanical path to make changes to the torch movement. Adjustments require time to retool the equipment for the next weld. The single-purpose design of the equipment makes intricate welding applications prohibitive if not impossible. Fixed automation welding systems equipment commonly includes operator controls, a torch positioner/holder, and a workpiece positioner/holder.

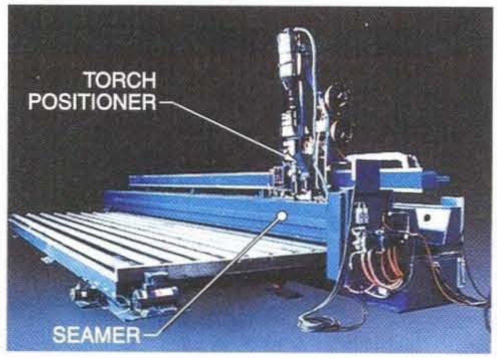
Operator Controls. Operator controls are used to start and stop the welding cycle. The operator controls may be connected to a programmable logic controller (PLC), which in turn controls the positioners and the welding equipment. The PLC sequences through the weld cycle, controlling when to move the torch, start the arc, feed the wire, and turn on the shielding gas, as well as other welding sequences. Some welding equipment uses internal controls rather than PLCs to control the welding equipment.

A torch positioner is a fixed-path mechanical apparatus that moves the torch in a specified path.

Torch Positioner/Holder. Fixed automation equipment such as seamers and orbital welders use a torch positioner, or holder. A *torch positioner* is a fixed-path mechanical apparatus that moves the torch in a specified path. A seamer is designed to weld linear seams in rolled tubes or flat plates. When a torch positioner is used on a seamer, it keeps the torch on a linear path along the joint and maintains a constant rate of speed. See Figure 29-2. A PLC or some other automated controller is typically used to direct the weld sequence.

A robot is a programmed path device used to position the torch and at times the workpiece.

Workpiece Positioner/Holder. The design of a workpiece positioner/holder needs to be quite sophisticated and elaborate to ensure that the simple path required by the torch can be maintained. The workpiece positioner must hold the workpieces without interfering with the path of the torch.



Pandjiris, Inc.

Figure 29-2. *A torch positioner used on a seamer keeps the torch on a linear path along the joint and maintains a constant speed.*

Workpiece positioners can be controlled manually, pneumatically, or hydraulically. The workpiece positioner may rotate or tilt by means of an electric motor that allows easier access to the weld seam.

The purpose of automation is to reduce manufacturing costs by increasing productivity and quality.

Flexible Automation Systems

A *flexible automation system* is a system that uses programmable movements of the torch and sometimes the workpiece. In flexible automation, programmed equipment guides the torch. The most common type of programmed device is the robot. A *robot* is a programmed path device used to position the torch and at times the workpiece. A robot can perform complex movements in order to follow a complex path. The robot can provide the fabricator with extended arc-on time. With the advances in electrical motors and motor control circuits, robots' speeds have almost matched those of fixed automation equipment, and the air cut time of the robot systems has been reduced. *Air cut time* is the time that a piece of equipment spends in the nonproductive activity of moving from one weld to another. In the past, fixed automation equipment provided much faster movements

than flexible automation equipment. The biggest advantage that flexible automation has over fixed automation is the reprogrammability of the robot movement, allowing for varied movement of the robot. This feature makes it easier and quicker to change weld settings, locations, and workpiece positions. The robot is capable of storing weld programs, which can quickly be changed, permitting a variety of parts and welds to be efficiently made by one robot.

In the past, flexible automation equipment was much more expensive than fixed automation equipment. However, with the increased variety and availability of flexible automation systems, the costs have become comparable. A flexible automation system typically incurs additional costs for the fixture designs and tooling associated with flexible automation systems.

An additional cost to the users of flexible automation systems is the cost associated with training. Operators, programmers, and maintenance personnel all must be trained in the proper use of the robot. In each case, the most efficient and beneficial training is to train process experts—welders—on how to operate and program the robot.

The components of a robot welding system (robot cell) used for flexible automation consist of a robot controller, robot manipulator, teach pendant, operator controls, and workpiece positioner.

Robot Controller. The robot controller provides the control for the servomotors and communicates with the welding equipment and other equipment in the system. A *servomotor* is an AC or DC motor with encoder feedback to indicate how far the motor has rotated. AC servomotors provide higher speeds and torques than DC servomotors and are the preferred method of control for robotic systems. With encoder feedback technology, AC servomotors provide faster and more accurate movement than the stepper motors used in the past. Stepper motors would rotate 360° in stepped increments, with an accuracy of .5°. AC servomotors can be controlled with an accuracy of .1°, without the need for the complex driving circuits associated with stepper motors.

The robot controller directs the starting and stopping of the servomotors as well as the rate of speed and acceleration of each servomotor. See Figure 29-3. The robot controller not only controls movement of the manipulators from point to point but also controls the path of the torch from point to point. Controlled movement paths may be linear (straight line) or circular (curved line).

The robot controller controls the movement of the manipulator from point to point and the path of the torch from point to point.

Robot Controller
Figure 29-3

The Lincoln Electric Company

Figure 29-3. *A robot controller is used to direct the starting, stopping, speed, and acceleration of the servomotors.*

A robot controller may control more than the servomotor in the manipulator, it may also control servomotors in the workpiece positioner and other equipment in the robot cell. Some robot controllers can control as many as 16 servomotors simultaneously for a synchronized motion. The robot controller must accelerate and decelerate each servomotor individually to maintain the controlled path at the tool center point (TCP). Advanced software and digital hardware are typically required to continually adjust the servomotors to the correct speed, acceleration, and deceleration.

The robot manipulator is the robot arm and consists of a base and several links and joints (or axes).

Robot Manipulator. The robot manipulator is the robot arm. A servomotor moves the robot manipulator from one point to another. The robot manipulator consists of a base and several links and joints. The base provides the mounting for the robot manipulator, much like a human torso. The links are the arm structures, similar to a human upper arm and forearm. The joints slide and rotate to allow the movements of the links, just like the human shoulder, elbow, or wrist. The joints of the robot manipulator are referred to as axis joints. Thus, a six-axis robot will have six axis joints.

The robot manipulator is the most important part of the robot cell design. Manipulators can be found in many different configurations, sizes, and speeds. Early robot manipulators, such as the rectilinear robot manipulator, were designed for easy control. These robot manipulators were large and slow, but easy to design and control. Rectilinear robot manipulators are still used for some spot welding applications, but are limited in their access to various welding positions.

A teach pendant is the input method that the robot programmer uses to create robot movement programs.

The most common configuration for a welding robot is a six-axis articulated robot manipulator driven by AC servomotors. See Figure 29-4. The servomotor provides the speed and repeatability needed for the welding operation. An articulated configuration allows the arm link and wrist joints to be small and compact. A small and compact joint can be easily maneuvered into tight areas.

Robot Manipulator
Figure 29-4

Motoman, Inc.

Figure 29-4. *A common configuration for a welding robot is a six-axis articulated robot manipulator.*

Welding manipulators are usually only required to lift small, light loads, but they must be able to move the loads quickly and with high repeatability. Most manipulators can return to a programmed point within approximately .004″, which gives the manipulator a .004″ repeatability factor.

Teach Pendant. The teach pendant and the robot controller are the brains of the robot welding system. A *teach pendant* is the device that the robot programmer uses to create robot movement programs. See Figure 29-5. The programmer uses the teach pendant to move the manipulator in either the axis plane or the Cartesian coordinate plane. See Figure 29-6. Axis motion is created by each axis servomotor individually creating movement to

position the TCP at the point programmed. Points in the Cartesian plane are found using the Cartesian coordinate system. The *Cartesian coordinate system* is a system of locating points in space defined by perpendicular planes. The Cartesian coordinate system uses a three-dimensional box with a horizontal X direction, a vertical Y direction, and a depth Z direction. The robot controller controls all of the axis servomotors simultaneously in order to maintain a straight-line X, Y, or Z direction when moving the manipulator. This type of motion allows the programmer to easily position the TCP to the point programmed because the movement is similar to that of a human welder.

Motoman, Inc.

Figure 29-5. *The teach pendant is the input method that the robot programmer uses to move the robot and create robot programs.*

Three methods of programming, or teaching, a robot are the lead through method, off-line programming, and the walk through method. The lead through method is used for teaching most robots. Off-line programming requires an experienced programmer. Walk through programming is rarely used any longer.

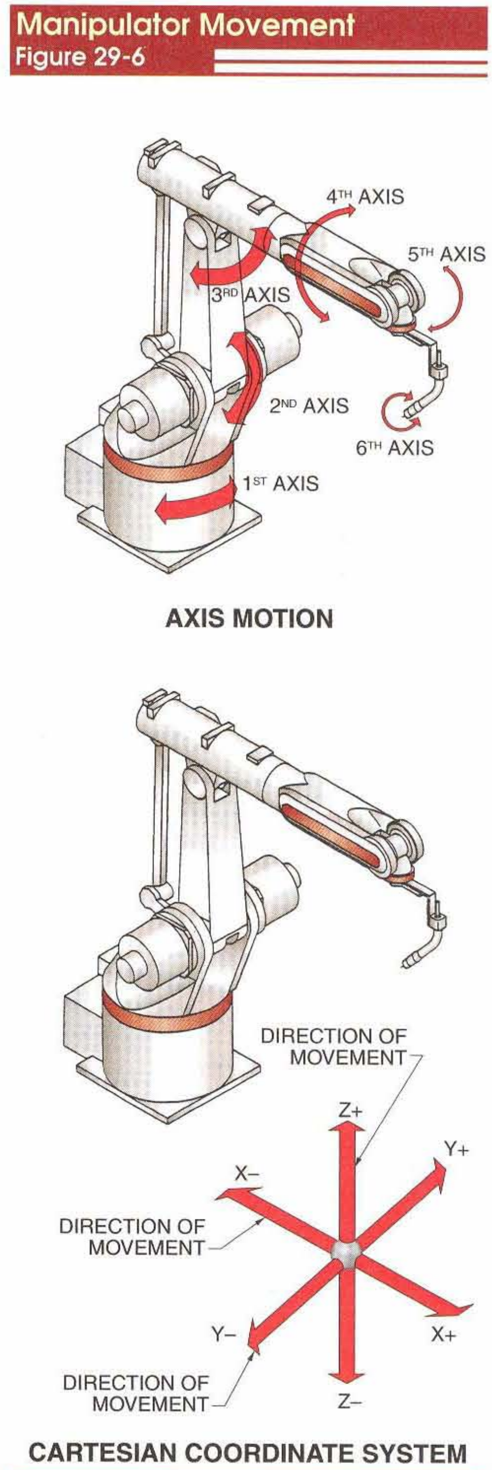


Figure 29-6. *Robot manipulator movement is produced by axis motion specified using the Cartesian coordinate system.*

Newer robot systems use off-line programming software to create robot programs. Off-line programming software is run on a PC, which simulates the robot work cell. See Figure 29-7. When the program is complete, the programmer downloads the program to the robot to be verified and

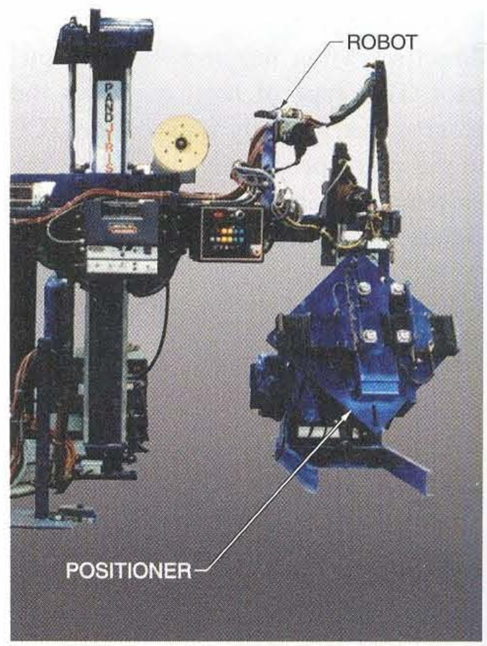
run. This type of programming reduces the amount of downtime needed to program or modify a robot.

Operator Controls. Operator controls are the switches and buttons used by the operator to control the operational sequence of the robot. These controls set the robot into automatic mode or teach mode. The operator may use these controls to initiate or change welding cycles or programs. Some manufacturers refer to the operator controls as start stations because the robot operational sequence is started from these panels using a start pushbutton.

The most important part of the operator controls is the emergency stop button. Each operator control panel must have an emergency stop button to stop the robot immediately in case of a dangerous situation.

Workpiece Positioner. The addition of workpiece positioners allows more efficient positioning of the weld joints for higher speeds and better weld quality. See Figure 29-8. Due to the simple paths of the torch positioner, the workpiece positioners/holders can become quite sophisticated and elaborate. They need to hold the workpieces without interfering with the path of the torch system. Some workpiece holders are manually operated while others are pneumatically or hydraulically controlled.

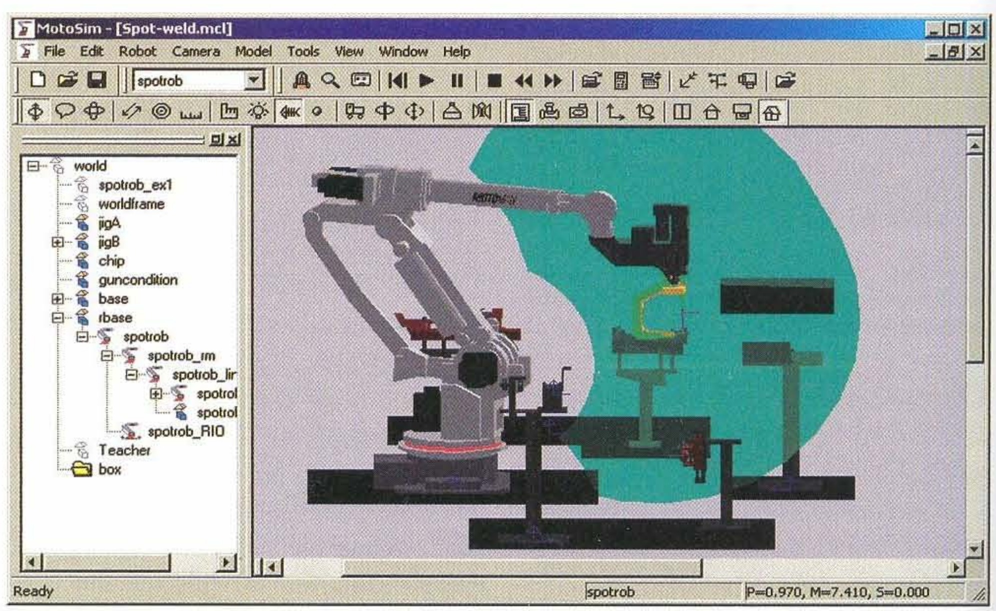
Some workpiece positioners may be controlled by the robot controller. These systems provide a tightly integrated robotic system that allows the programmer infinite positions for the workpiece. Some systems allow the



Pandjiris, Inc.

Figure 29-8. *Workpiece positioners allow more efficient positioning of the weld joints for higher speeds and better weld quality.*

Figure 29-7. *Off-line programming software is used to create robot programs that replicate the motions a robotic system must make.*



Motoman, Inc.

workpiece positioner to move at the same time that the robot is moving and still maintain a straight line or circular welding path. This type of motion is sometimes referred to as synchronized motion. The motion is similar to holding a clipboard in one hand and a pencil in the other hand and drawing a perfectly straight line.

Adaptive Controls. The robot system may include optional equipment to aid in adapting the robot controls to particular weld environment factors. Robots cannot see, feel, or hear like a human welder. If the operator or tooling cannot place the part to the same position repeatedly, equipment capable of adjusting the weld is needed. Adjustments may be made to the welding process or to the motion path of the robotic system. Adjustments are made through a robot interface.

The addition of a robot interface creates a close coupling between the robot controller and the welding equipment. The robot interface provides the communication path for the robot controller to the welding power source, gas solenoid, and wire feeder. Many robot interfaces are capable of adjusting the welding parameters to maintain a constant voltage at the welding arc. Constant-voltage welding controls adapt to the changing conditions of the weld by continually monitoring the weld voltage and adjusting the welding current to maintain a set arc length. These types of systems are used in most robotic GMAW welding processes. A constant-voltage weld controller can adapt the process to overcome small deviations in the weld joint. Similar controls are used in the robotic pulsed GMAW process. Some advanced adaptive controllers eliminate the need for an interface panel and provide all the necessary inputs and outputs to the robot system.

In adaptive pulsed GMAW, several of the pulsed parameters must be manually changed in order to maintain a constant arc length. Process adjustments are the preferred method for adapting the robotic welding system to environmental deviations, as they usually do not affect the welding cycle time of the robotic system.

Some welding environments require greater adjustments than can be obtained through the welding process parameters. These welding environments require adjustments to the motion path of the robotic system through a touch sensor system. A touch sensor system can identify the amount of deviation from the position to which the workpiece was initially programmed. Touch sensors use a probe or the welding wire to touch the surface of the workpiece to identify the deviation from the programmed point. When the deviation is identified, the robot controller alters the original programmed points to match the workpiece deviation. The laser location system uses a laser beam to locate the workpiece instead of a probe or the welding wire. A laser location system reduces errors caused by bending of the probe or the welding wire.

The robot interface provides the communication path for the robot controller to the welding power source, gas solenoid, and wire feeder.

The application of touch sensors slows the cycle time of the weld program, which is generally not acceptable in high-production facilities. However, the tooling needed to maintain the weld joint in position and within tolerance may be prohibitively costly to the weld producer. These cost factors may force the weld producer to slow the weld cycle and introduce a touch sensor into the system.

Thru arc seam trackers and laser seam trackers help identify any deviations of the weld seam while the robot is welding. Workpiece warpage during the welding process causes the welding seam to move, creating a deviation from the originally programmed welding path. Thru arc seam trackers identify these deviations by monitoring the welding current and voltage. As the welding torch weaves

along the weld joint, the current and voltage change, causing a specific pattern of increased current and voltage. The seam tracker follows the pattern and adjusts the weld path to repeat the pattern of a "known good weld."

The thru arc seam tracker monitors the deviations in current and voltage by weaving along the weld joint during welding and sending signals (current and voltage measurements) to the robot controller. The weave pattern must be programmed into the robot by the programmer. While the weave pattern allows the robot to relearn the program and alter its trajectory to maintain a quality weld, the weaving action slows the welding process and may cause undercut to the joint. Laser seam trackers use a laser beam to sweep across the weld path looking for weld seam deviations. Laser seam trackers do not need to weave the welding wire along the weld joint, which allows for an increased welding speed and reduced chance of undercut from the weaving action. The laser systems require more care and maintenance to prevent damage to the optical laser lens and receiver.

Robotic GTAW and PAW systems may also include motorized torch adjustments. These systems monitor the arc voltage and adjust the height of the torch by moving the torch up and down on a slide mounted between the torch mount and the torch. These systems usually add bulk to the torch and thus reduce the ability to access certain weld joints.

The majority of arc welding robots are designed for the GMAW process, which provides arc control and filler wire control simultaneously.

AUTOMATIC WELDING EQUIPMENT

Automatic welding equipment used for automatic welding and robotics is generally semiautomatic equipment outfitted to perform automatic operations. For example, for the GMAW process, automatic welding equipment includes a welding power source, wire feeder, torch, and shielding gas system.

Automatic welding equipment includes a welding power source, wire feeder, torch, and shielding gas system.

The power source used is typically the same type of power source used for semiautomatic welding. The wire feeder is modified to accommodate the sequence commands needed for the automated welding process. Robotic systems use torches and a shielding gas system specifically designed to be mounted and operated on a robot manipulator.

Torch mounting includes breakaway plates or crash detection mounts so the torch breaks away or the robot stops if the torch hits something while moving. Torch mounts protect the robot manipulator from severe damage.

Many robot controllers provide the signals for the gas solenoid, wire feed speed, and welding voltage through arc start and arc end parameters programmed into the controller. These signals need to be communicated to the welding equipment. Some welding systems integrate the power source, wire feeder, and shielding gas system into one piece of equipment. For example, submerged arc flux delivery and recovery systems are added to the robotic system to provide solid flux for SAW. Extra equipment, such as additional torches or multiple shielding gas systems, may be required for some automatic welding processes.

The American Welding Society maintains standard AWS/NEMA D16.2/D16.2M, *Guide for Components of Robotic and Automatic Arc Welding Installations,* which details the components within robotic and automatic welding systems.

Welding Process Parameters

The majority of arc welding robots are designed for the GMAW process. The GMAW process provides arc control and filler wire control simultaneously. See Figure 29-9. The weld programmer only needs to control the placement of the wire in the weld joint and ensure the use of the correct welding parameters.

Fanuc Robotics North America

Figure 29-9. *The GMAW process provides arc control and filler wire control to the robot simultaneously.*

The GMAW process in automated welding is slightly different from the GMAW process in manual welding. The goals in automatic welding are high travel speed with maximum weld penetration and minimum weld spatter. The main welding parameter that must be controlled is the weld travel speed. In manual welding, weld travel speeds rarely exceed 15 inches per minute (ipm). In automatic welding, manufacturers strive for 30 ipm to 40 ipm and with special GMAW processes may attain 50 ipm to 60 ipm.

To achieve these goals in a practice setting, some of the GMAW welding parameters must be adjusted to optimize the weld. The angle of the torch must be adjusted to a 15° push angle to allow for maximum penetration at maximum weld travel speeds. The wire feed speed and the welding voltage must be adjusted for the material to be welded and the weld joint to produce a GMAW spray transfer arc at manual welding travel speeds. After a good arc at manual welding travel speeds is achieved, the weld travel speed can be increased to production speed levels. These weld parameters offer the speed and deposition rate of the GMAW spray transfer process with the penetration and control of GMAW short circuiting transfer. The arc produces a distinctive sound that some have termed a "GMAW production spray."

WORK AREA AND SAFETY

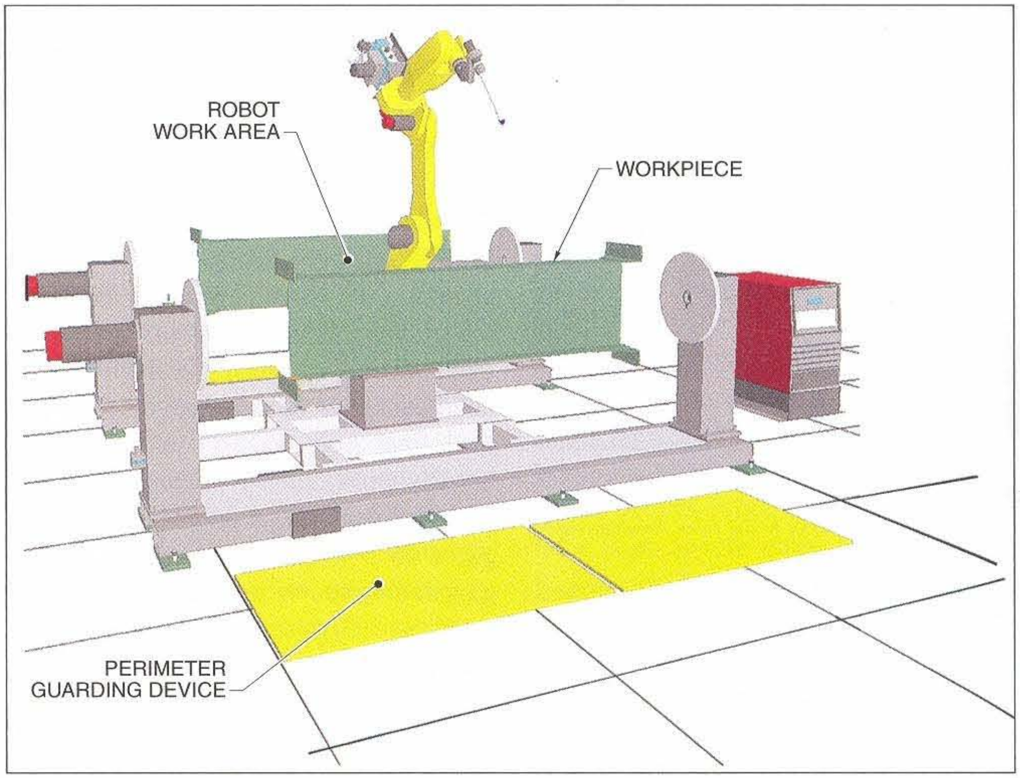
The robot work area poses potential dangers for maintenance personnel, operators, and programmers. Robot operators, programmers, installers, and manufacturers must be aware of potential dangers. A primary hazard posed by the robot is through mechanical movement of the robot. The robot may hit, trap, or crush a person. A safeguarded space is established to protect personnel from hazards. Protection is usually provided by perimeter guarding devices such as fencing and safety gates to prevent access to the safeguarded space without conscious action. See Figure 29-10. Additional presence-sensing devices, such as safety mats, should be installed within the perimeter guards to ensure that no personnel enter the safeguarded space during operation of the robot. Protection from welding is provided by screens.

All personnel require protection from the potential hazards that may occur as a result of interactions with the robot. The Robotic Industries Association (RIA), in conjunction with ANSI, maintains ANSI/RIA R15.06, *Industrial Robots and Robot Systems — Safety Requirements.* All companies involved with robotics should follow these safety requirements.

The ANSI/RIA standard separates the robot work area into the operating space of the robot, the restricted space, and the safeguarded space. The operating space is the space where the robot runs the processes associated with the robot. In the case of welding, this work area includes the workpiece and tooling. The restricted space is the space that the robot operates in with limiting devices attached to the system. Without limiting devices, the robot would move in its maximum space, or work envelope, which is the space encompassing the maximum movement of the robot, the end-effector, the workpiece, and the attachments. The safeguarded space confines the mechanical hazards

Robotic welding equipment can be dangerous, always follow the safety requirements found in the Robotic Industries Association (RIA) standard ANSI/RIA R15.06, Industrial Robots and Robot Systems—Safety Requirements.

Figure 29-10. *Protection from the robot work area is provided by perimeter guarding devices to prevent access to the safeguarded space without conscious action.*



The Lincoln Electric Company

from all personnel not operating or teaching the robot. The safeguarded space cannot be smaller than the restricted space.

The ANSI/RIA standard calls for proper training of all personnel. Training includes safeguard training, teacher training, operator training, maintenance training, and installer training. The end user of the robot and robot system is responsible for training their employees and maintaining training documentation. With proper training and protection, robot system hazards can be significantly reduced or eliminated. Guidelines for the levels of qualification and safety and health considerations may be found in AWS D16.4, *Specification for the Qualification of Robotic Arc Welding Personnel.*

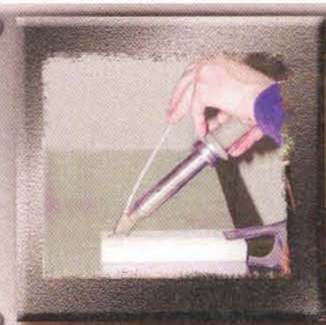
The American Welding Society also publishes AWS D16.3M/D16.3, *Risk Assessment Guide for Robotic Arc Welding,* which includes guidelines for risk assessment, robot classification, and potential hazards primarily associated with arc welding robots and robotic arc welding systems.

POINTS TO REMEMBER

1. A torch positioner is a fixed-path mechanical apparatus that moves the torch in a specified path.
2. A robot is a programmed path device used to position the torch, and at times the workpiece.
3. The robot controller controls the movement of the manipulator from point to point and the path of the torch from point to point.
4. The robot manipulator is the robot arm and consists of a base and several links and joints (or axes).
5. A teach pendant is the input method that the robot programmer uses to create movement programs.
6. The robot interface provides the communication path for the robot controller to the welding power source, gas solenoid, and wire feeder.
7. The majority of arc welding robots are designed for the GMAW process, which provides arc control and filler wire control simultaneously.
8. Automatic welding equipment includes a welding power source, wire feeder, torch, and shielding gas system.
9. Robotic welding equipment can be dangerous, always follow the safety requirements found in the Robotic Industries Association (RIA) standard ANSI/RIA R15.06, *Industrial Robots and Robot Systems—Safety Requirements.*

QUESTIONS FOR STUDY AND DISCUSSION

1. What are the two categories of automation?
2. What manual welding process is most commonly adapted for robotic welding?
3. What is the purpose of torch mounts?
4. Why is fixed automation preferable to manual welding processes?
5. What are the components of a robotic welding system?
6. What are the two torch motion patterns?
7. Why is a robot interface added to a robotic welding system?
8. How does the mechanical movement of the robot pose hazards to operators, programmers, and other personnel?
9. How are personnel protected from the hazards posed by the robot?



Plastic Welding 30

Other Welding Processes

Welding is often used to fasten parts in the fabrication of plastic products. Welding can be used for assembling such products as storage tanks, boxes, and other containers. Installation of plastic pipe and ductwork with welding is also common. The manufacture of many custom plastic products is made possible by plastic welding techniques.

TYPES OF PLASTICS

Most plastics are identified by trade names or by the principal compound from which they are made. Plastics are broadly grouped as thermosetting plastics and thermoplastics.

Thermosetting plastics soften only once when exposed to heat. Once thermosetting plastics have been molded into a particular shape and cured (hardened), no subsequent heating can soften them again. Thermosetting plastics are not weldable. They are joined by mechanical methods, principally adhesive bonding. Typical thermosetting plastics are ureas, phenolics, melamines, polyesters, silicones, epoxies, and urethanes.

Thermoplastics can repeatedly soften when heat is applied. These plastics can easily be welded. There are many kinds of thermoplastics, such as acrylics, polystyrenes, polyamides, polyfluorides, and vinyls. Generally the more common thermoplastics used where welding is involved are polyethylene, polyvinyl chloride (PVC), and polypropylene. Welding these types of plastics produces seams that are as strong or stronger than the materials being bonded. Compressed air is best for welding PVC and several other types of plastics. Both the gas and compressed air are controlled by regulators to provide the correct pressure flow. See Figure 30-1.

THERMOPLASTIC WELDING CHART

Thermoplastic Material	Welding Temperature*	Welding Gas
PVC	525	Air
Polyethylene	550	Nitrogen
Polyethylene	575	Nitrogen
Penton	600	Air
ABS	500	Nitrogen
Plexiglas™	575	Air

* °F

Figure 30-1. *The welding gas used is determined by the type of thermoplastic material to be welded.*

PLASTIC WELDING TECHNIQUES

Plastic welding is similar to metal welding in that localized heat is used to produce fusion. Joint preparation requirements such as proper fit-up and root opening, joint design, and beveling are required in plastic welding as

Bevel all edges to secure a proper weld joint. Interlocking the corners produces the best results on corners.

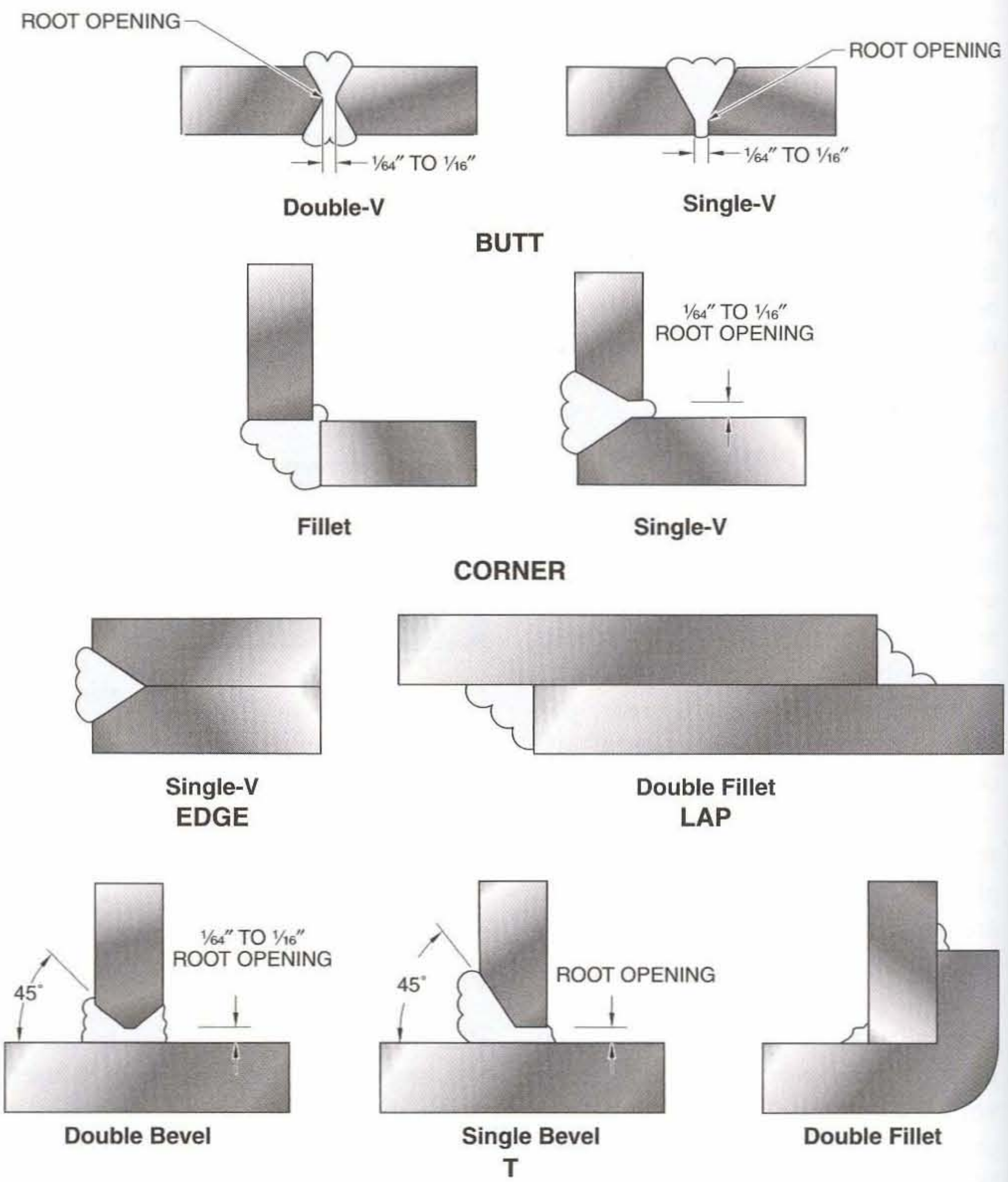
in metal welding, with one significant difference. In metal welding, a sharply defined melting point develops and the base material and filler material melt and flow together to form the weld joint. However, plastics are poor heat conductors, and consequently they do not readily melt and flow. To achieve a permanent bond, the filler material and base materials must be heated to a point at which the materials will fuse together, but not so high that the plastic decomposes.

Joint Preparation

The types of joints used in plastic welding are the same as those used in metal welding—butt, corner, edge, lap, and T. The edges of the joints are beveled to provide a sufficient area on which to form a good bond. The beveled edges should have a groove angle of 60° with a root opening between 1/64″ and 1/16″, although the root opening may be deeper if a larger filler material is required. See Figure 30-2.

Figure 30-2. *The types of joints used for plastic welding—butt, corner, edge, lap, and T—are the same as those used for welding metal.*

Plastic Welding Joints
Figure 30-2



⚠ WARNING

Some plastic materials, such as vinyl, produce HCl gas or obnoxious odors. Polyvinyl chloride produces poisonous fumes. Precautions must be taken to avoid inhaling these fumes. If necessary, a respirator should be used.

Welding Procedure

Select the correct shape tip and insert in the gun. Guns should be able to supply a temperature varying from 400°F (204°C) to 600°F (316°C) or more (up to 925°F [496°C]). Different materials and different plastic thicknesses have differing heat requirements.

Set the air or gas pressure according to the plastic manufacturer's recommendations. Although the wattage of the heating element determines the range of heat, the air or gas pressure determines the actual amount of heat at the tip. See Figure 30-3.

AIR PRESSURE SETTINGS

Element*	Air Pressure†	Temperature‡
320	2–3	400
340*	2–3	410
350	2½–3½	430
450	3–4	540
460*	3–4	600
550	4–5	700
650	4½–5½	800
750	5–6	860
800*	5–6	900

* Note: Three-heat unit with a rotary heat selector switch: (in W) Low – 340 W, Medium – 460 W, High – 800 W
† psi
‡ °F 3/16" from tip

Figure 30-3. *The air or gas pressure setting determines the amount of heat at the tip during welding.*

During the welding cycle, 3 psi to 5 psi of pressure should be applied to ensure weld integrity. Exerting excessive pressure on the filler material may cause excessive stretching, particularly when welding vinyl. The length of the filler used should be the same as the length of the weld. Equally important is to avoid overheating the weld area as the filler material and the base material can char and discolor, resulting in an unacceptable weld. Underheating is also objectionable since it produces a cold weld that has poor tensile strength.

Check the weld by bending a test weld 90°. If the weld is made properly, the weld beads will not separate from the base material nor will it be possible to pry the filler material out of the weld when cooled. A cross-section of the test weld also reveals whether complete penetration has occurred. See Figure 30-4.

Plastic welding should always be done in a well-ventilated area. Follow the manufacturer's recommendations for safe practices when welding specific types of plastics. The basic welding processes used for plastic welding are hot gas, heated-tool, and induction. With some restrictions, friction welding can also be used.

Use filler material of the same composition as the base material.

Weld plastics only in a well-ventilated area. If a ventilation system is not in place, portable ventilating equipment should be used to ensure adequate ventilation during welding.

Plastic Weld Cross-Section
Figure 30-4

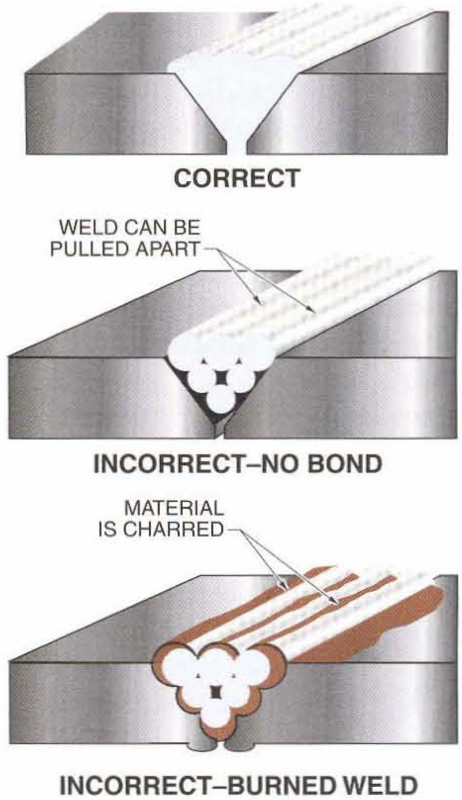


Figure 30-4. *A cross-section cut through a test weld shows the amount of penetration that has occurred.*

Do not allow the surface to char or discolor.

HOT GAS WELDING

Hot gas welding is accomplished with a specially designed gun containing an electrical heating unit. A stream of compressed air or inert gas (nitrogen) is directed over the heated element, which then flows out of the nozzle and

onto the surface of the material being bonded. The gun permits the use of several different tips for different welding operations. The type of tip used depends on the plastic welding application. Four types of tips are designed for high-speed welding: tacker, round, flat, and V-shaped. The increased speed of a high-speed tip is achieved by the design of the tip, which holds the filler material and applies the needed pressure as the weld is made. A tacker tip is used for tack welding. See Figure 30-5.

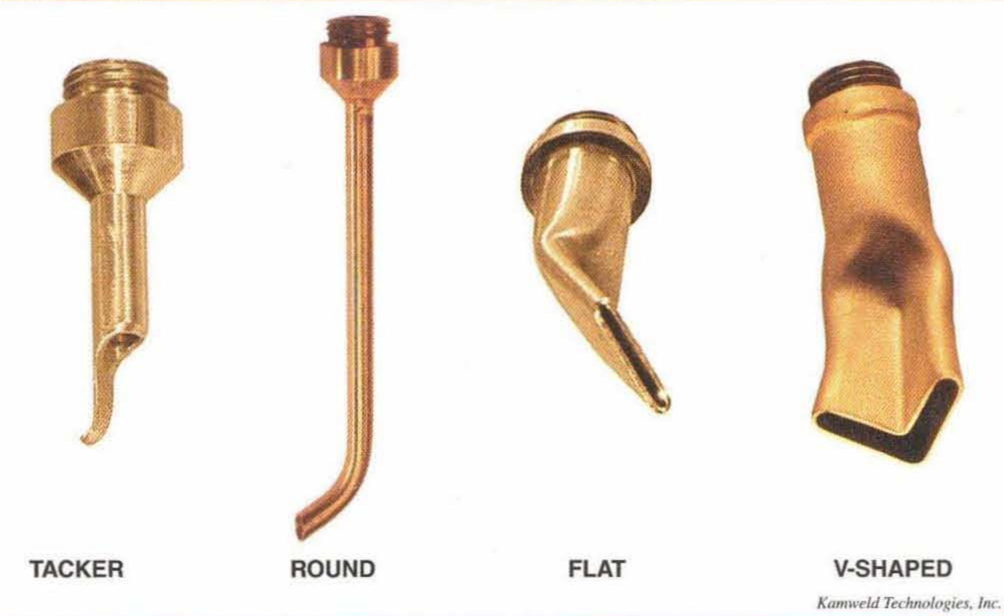
Hand Feed Welding

The technique for hand feed welding of plastic is similar to oxyacetylene welding of metals. The gun is held in one hand and the filler material is held in the other. The correct filler material is selected and cut. The filler material should be of the same basic composition as the base material. Either flat, round, or triangular strips may be used. Triangular strips are particularly advantageous in V or fillet welds since the area can be filled with one pass. One-pass welding reduces welding time and minimizes the chances of lack of fusion, which may occur with multiple passes of round strips. See Figure 30-6. The hand feed operation for welding plastic is as follows:

1. Hold the tip of the gun about 3⁄16″ to ½″ away from the start of the weld and begin a fanning motion. Place the filler material in a vertical position so the heat from the gun is directed on both the filler material and the base material.
2. When both the base material and the filler material become tacky, press the filler firmly into the joint and bend it back at a slant with the point away from the direction of welding.
3. As the gun is moved along the seam, continue to exert pressure on the filler material to force it into the groove. Maintain a constant fanning motion at a 45° angle so both the filler material and the joint area are heated equally. When welding heavy-gauge plastic with filler material, most of the heat should be directed on the joint.

Figure 30-5. *Several types of tips are available for hot gas welding of plastic.*

Plastic Welding Tips
Figure 30-5



Kamweld Technologies, Inc.

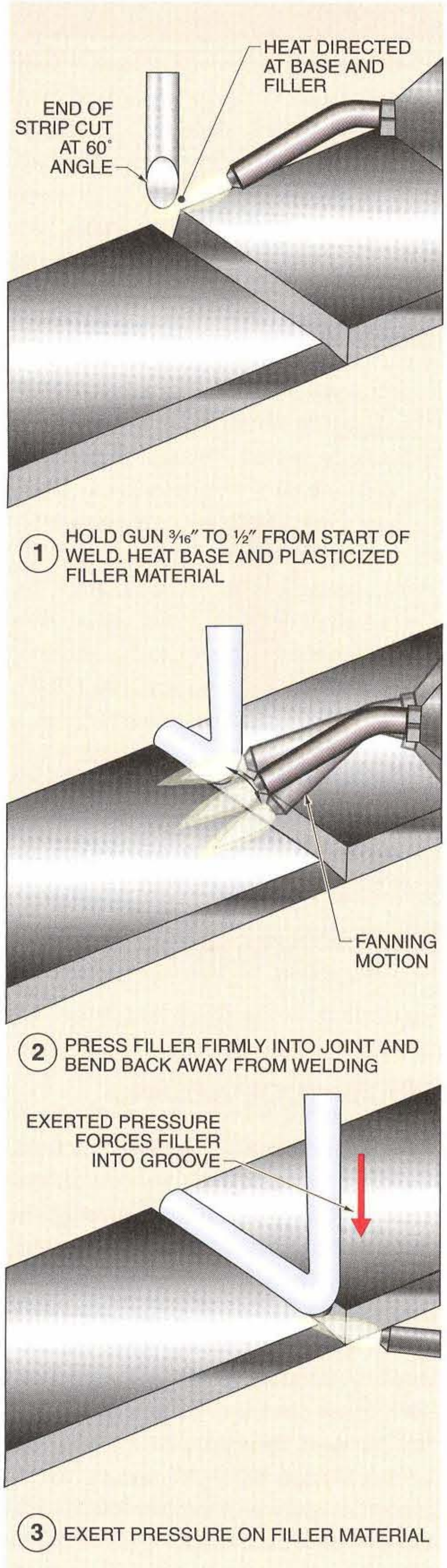


Figure 30-6. *When the base material and the filler material become tacky, press the filler firmly into the joint, continuing to heat the area and exert pressure as the welding progresses.*

High-Speed Welding

The speed of making welds can be substantially increased using the high-speed welding process. As-welded, round, and triangular filler materials are often used for high-speed welding. Filler material must be cut into the required lengths, with one or two inches allowed for trimming. See Figure 30-7. The high-speed welding procedure is as follows:

1. Insert the filler material into the high-speed tip. Start the weld by holding the tool at a 90° angle and tamping the broad shoe of the tip on the surface until the first inch of the filler adheres firmly to the base material. Hold the high-speed welding tool at a 45° angle to the work and press the end of the filler into the weld. Feed the filler material manually until the weld bead has been sufficiently started.
2. Maintain an angle of 45° while moving forward along the seam. Once the welding operation is under way, a firm downward pressure of 3 lb to 5 lb is placed on the gun to automatically feed the filler material into the preheated tube.
3. Keep the gun moving at a sufficient speed. Correct speed can be observed by the formation of flow lines on both sides of the filler material. Insufficient speed causes the filler material to stretch because of built-up excessive heat. This condition can be corrected with a quick tamping motion of the shoe as used in starting the weld.

Use a fanning motion to ensure uniform heat distribution over the filler rod and the edges of the joint.

Kamweld Technologies, Inc.

Parts to be joined by high-speed welding should be firmly clamped to prevent movement out of position.

High-Speed Plastic Welding Procedure
Figure 30-7

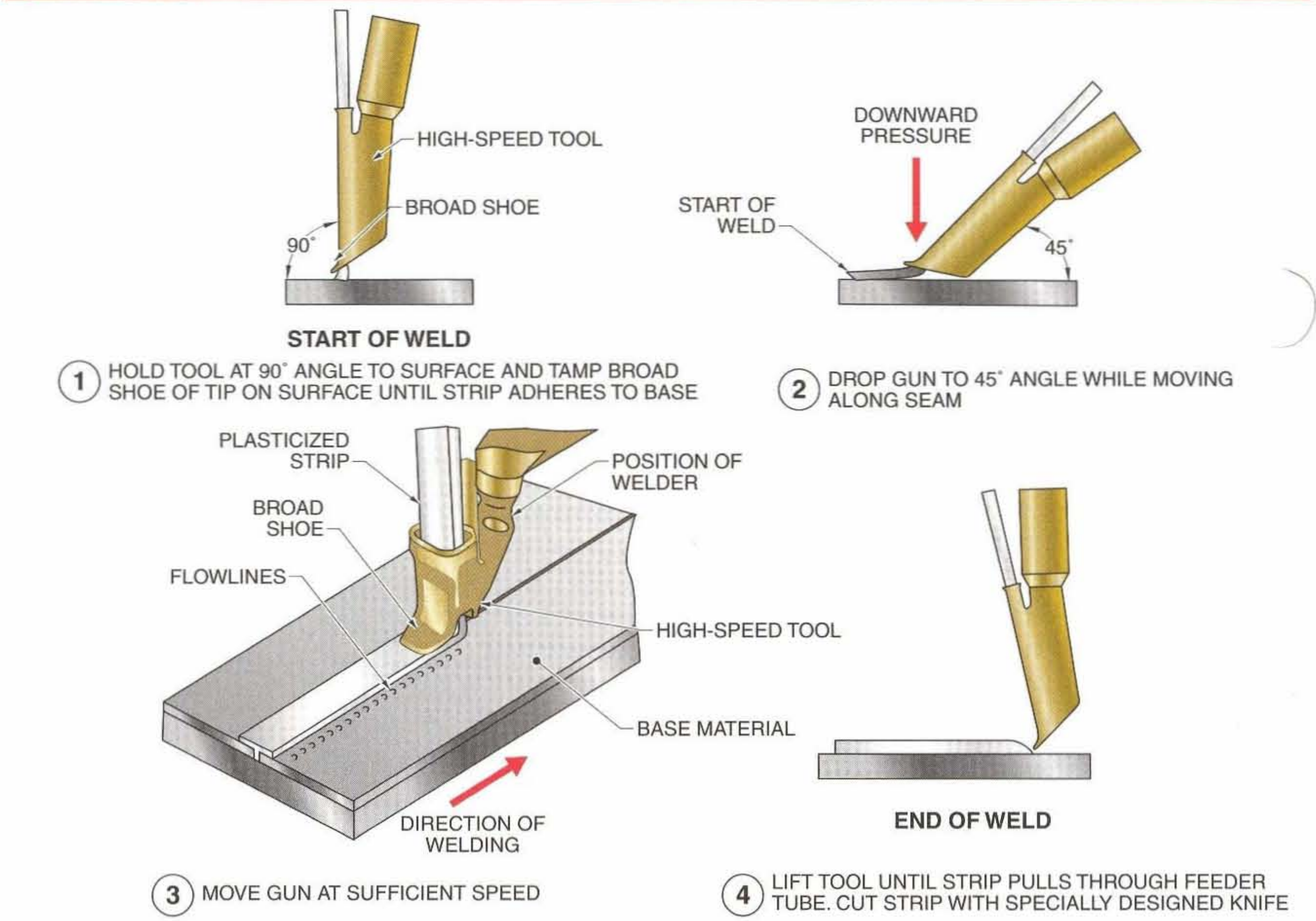


Figure 30-7. *Special tips can be used for high-speed welding to hold the filler material in the correct position; however, the proper procedure must also be used to ensure sufficient penetration and strength.*

Tack Welding

Tack welding is used to fuse materials together prior to welding in order to eliminate the use of clamps or fixtures. A tacker tip is used for tack welding and is used with all types of joints to be welded. See Figure 30-8.

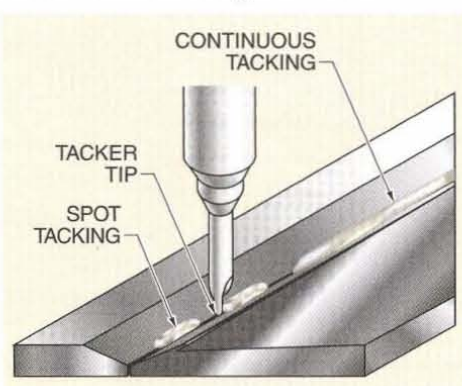


Figure 30-8. *Common tack welding techniques used to eliminate the need for clamps and fixtures during welding include continuous tacking and spot tacking.*

HEATED-TOOL WELDING

In the heated-tool (heated surface) welding process, heat for welding is generated in a hot tool. The edges to be joined are heated to the proper temperature, then brought into contact and allowed to cool under pressure. The edges of the plastic sheet are softened with some heat-producing unit such as an electrical strip or bar heater, hot plate, or resistance-coil heater. The heater should be aluminum or nickel since hot steel and copper have a tendency to decompose plastic. The heated-tool welding technique is commonly used for joining sections of pipe and tubing and in the assembly of many molded articles.

Heated-Tool Welding Procedure

The heated-tool welding procedure is a machine process in which heat is applied by holding the edges in contact with the heating unit until the surface is softened. When the material has reached a molten state, it is removed from the heater and the edges are quickly pressed together. The pressure on the pieces should be enough to force out air bubbles and form a solid contact. Normally, pressures of 5 lb to 15 lb produce good bonded joints. Pressure can be applied by hand or, in production work, with jigs. The pressure must be maintained until the weld has cooled. The most important factor in securing sound welds by the heated-tool technique, outside of proper softening of materials and firm contact, is the elapsed time between removing the pieces from the heating unit and joining them together. The elapsed time interval should be as short as possible to prevent any degree of solidification before the edges come in contact.

INDUCTION WELDING

In induction welding, or sonic welding, heat is generated by causing a high-frequency current to flow into a metal insert placed between the areas to be joined. Although induction welding is one of the fastest methods of joining plastic, its greatest limitation is that the metal insert must remain in the weld.

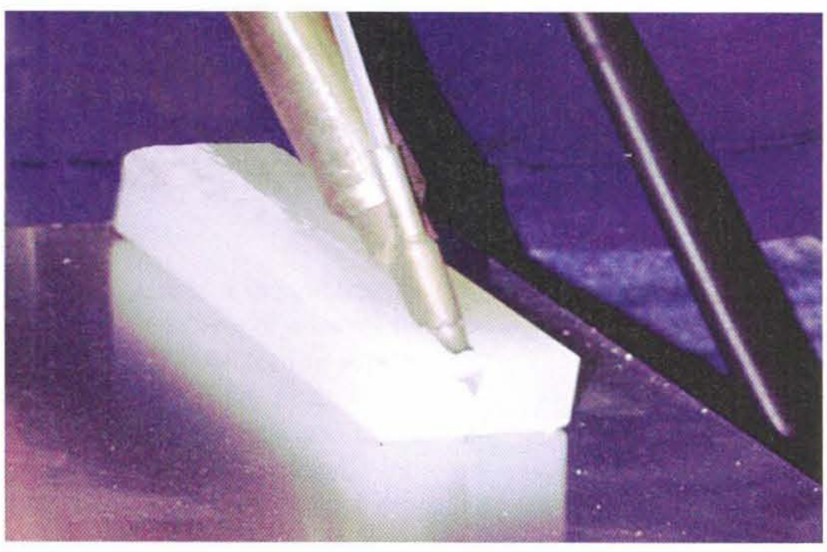
Metal inserts usually consist of metallic foil, wire coil, wire screen, metallic conducting particles, or some other configuration of conductive metal. Inserts must be placed in the interface so they are not exposed to air; otherwise, rapid heating is induced, which may cause the inserts to disintegrate. Fusion occurs only in the area immediately near the insert. When the edges become soft, uniform pressure is applied to bond them together.

As a rule, welds made by the induction process are not as strong as those obtained by other heating methods.

FRICTION WELDING

Friction welding, or spin-welding, consists of rubbing the surfaces of the parts to be joined until sufficient heat is developed to bring them to a fusing temperature. Pressure is then applied and maintained until the unit is cooled. In friction welding, one piece is held in a fixed, locked position and the other is rotated. When sufficient melt occurs, the spinning is stopped and the pressure is increased to squeeze out air bubbles and distribute the softened plastic uniformly between the surfaces.

The principal advantages of friction welding are the speed and simplicity of the process. However, friction welding is limited to circular areas and small items. Sometimes friction welding produces a flashing out of soft material beyond the weld area, but usually the excess flashing can be directed to the interior of the part if the weld is properly designed. Excess flashing can also be avoided by preventing the parts from overheating and by maintaining the proper pressure.



Kamweld Technologies, Inc.

A tack weld can be used in plastic welding to eliminate the need for clamps and fixtures.

POINTS TO REMEMBER

1. Bevel all edges to secure a proper weld joint. Interlocking the corners produces the best results on corners.
2. Use a filler material of the same composition as the base material.
3. Use a fanning motion to ensure uniform heat distribution over the filler material and the edges of the joint.
4. Do not allow the surface to char or discolor.
5. Weld plastics only in a well-ventilated area. If a ventilation system is not in place, portable ventilating equipment should be used to ensure adequate ventilation during welding.

QUESTIONS FOR STUDY AND DISCUSSION

1. What is the main difference between plastic welding and metal welding?
2. Why are thermosetting plastics not weldable?
3. At what range of temperatures are plastics generally welded?
4. What governs the degree of heat that is to be used in plastic welding?
5. What is the particular advantage of using triangular filler material over round?
6. How far from the surface should the gun be held when welding plastics?
7. Why is a fanning motion necessary in manipulating the gun over the weld joint?
8. Why should excessive pressure on the filler material be avoided?
9. What happens if insufficient heat is used when a welder is making a plastic weld?
10. What test can determine if a weld is made properly?
11. What precautions should be taken when welding plastics?
12. How does the high-speed plastic welding technique differ from the regular hot gas welding technique?
13. When using high-speed welding, why should the filler material not be allowed to remain in the feeder tube?
14. How is the heated-tool welding technique accomplished?
15. What is one of the main limitations of induction plastic welding?
16. How are plastic joints bonded by friction welding?

31 Destructive Testing

Destructive testing involves taking sample portions of a welded structure and subjecting them to loads until they fail. The nature of the test is dictated by the service requirements of the finished product. Destructive testing is performed on welds to qualify both welders and welding procedures; to develop manufacturing quality control acceptance specifications; and to determine if electrodes and filler metals meet the requirements of the specifications. Destructive testing is also used to measure residual stresses associated with welds. Several types of standardized destructive tests are used. Destructive test types and the location(s) of specimens in the weld joint are indicated in the controlling fabrication code or standard. Specimen preparation techniques are necessary for reliable test results.

DESTRUCTIVE TEST TYPES

Destructive tests are used to measure quality, strength, ductility, toughness, and hardness of welded joints. Destructive tests are relatively expensive since they involve preparing materials, making welds, cutting and often machining, and testing of specimens to failure, followed by interpretation of tests by qualified personnel.

Tests are used in specific applications to qualify welding procedures and welders. To qualify a welding procedure or welder, welds are made to welding procedure specification (WPS) parameters, cut into standardized sizes and shapes, and tested to destruction. The welding process, filler metals, and welding technique are selected to make the weld in the position required on the base metal used. Welding joint details and material thicknesses may not be exactly as used in making the production weld. Requirements vary between fabrication codes and standards so that test specimens are not always the same, nor are they taken from the same locations in a test weld. It is essential that the current edition of the controlling fabrication code or standard be followed when making test welds and test specimens, and when conducting destructive tests. Destructive tests consist of tensile, shear, bend, hardness, toughness, and break tests.

The current edition of the controlling fabrication code or standard must be followed when making test welds and test specimens, and when conducting destructive tests.

Tensile Test

A *tensile test* is a destructive test that measures the effects of a tensile force on a material. Tensile testing involves the placement of a weld specimen in a universal testing machine and pulling the piece until it breaks. Tensile force occurs when a mechanical load is applied axially (parallel to the axis) to stretch a test specimen. See Figure 31-1.

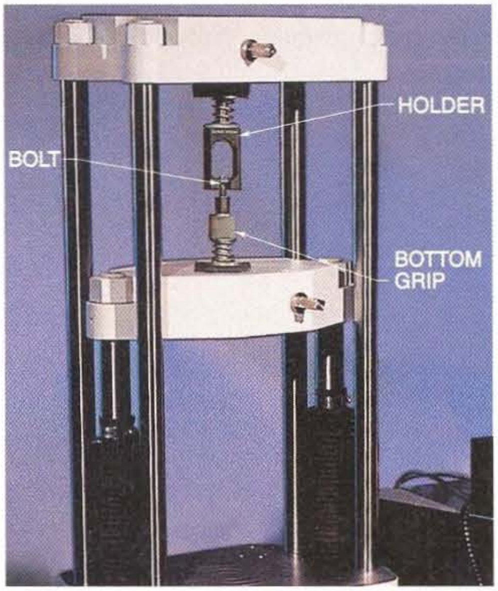


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Figure 31-1. *A universal testing machine is used to perform a tensile test on weld specimens, such as a bolt, to determine the tensile strength of the welds.*

The specimen is cut either from an all-weld area or from a welded butt joint for plate and pipe. The specimen for an all-weld area should conform to specific dimensions and it should be cut from the welded section so its reduced area contains only weld metal. See Figure 31-2.

The transition from the ends of the tensile specimen to the reduced section is either shouldered or made with a fillet. Shoulders and fillets minimize stress concentrations. This is particularly important for brittle materials because they are more likely to fail catastrophically at a region of high stress concentration. The longitudinal axis of the specimen and the specimen grips are symmetrical along

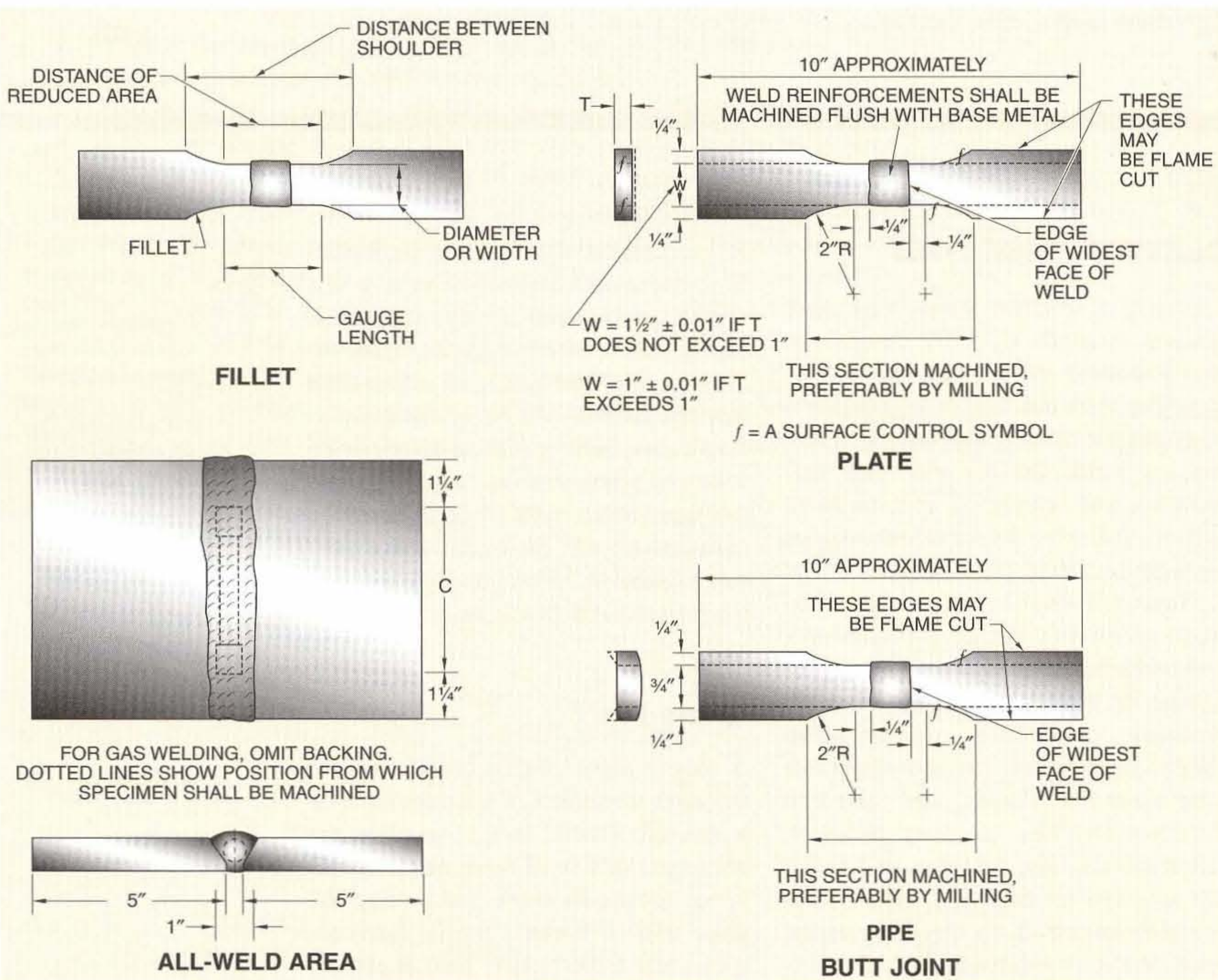

Figure 31-2. *A fillet is used on the tensile test specimen to remove stress concentrations. Specimens for all-weld areas must conform to specific dimensions. Butt welds are used for tensile tests on plate and pipe.*

the longitudinal axis of support to avoid the introduction of bending loads during the test. The gauge length (distance over which the elongation measurement is made) is always less than the distance between the shoulders. The most common gauge lengths are 2″ and 8″. The gauge length is normally marked on the specimen using a pair of center punch marks spaced a prescribed distance apart. The gauge marks are always an equal distance from the center of the length of the reduced section. The weld in a welded tensile specimen is always located at the center. Before the specimen is placed in the tensile machine, an accurate measurement should be taken of the gauge length.

Data recorded from weld tensile tests on a welding procedure qualification record (PQR) are maximum load, tensile strength, and failure location. In certain cases, percent elongation and percent reduction of area are also reported.

In addition to qualifying welding procedures and welders, the tensile test also provides information on the load-bearing capacities, joint efficiencies, strain-hardening properties, and ductility of welded joints. Tensile test results provide quantitative data that can be compared or analyzed and used in the design of welded structures. Fracture surface appearance at the failure location provides information on the presence and effects of discontinuities such as incomplete fusion, incomplete joint penetration, porosity, inclusions, and cracking.

A *tensile test machine* is a testing machine composed of two major components that are the means of applying the load to the specimen and the means of measuring the applied load. Some machines are designed for one type of testing only, for example machines that test chain and wire. Universal testing machines apply loads to test specimens in tension or compression.

In a universal testing machine, the load is applied mechanically to the specimen by means of a screw and gears, or it is applied hydraulically. The applied load is measured by a dynamometer (load cell) for mechanically driven machines and by a Bourdon tube for hydraulically driven machines. A *load cell* is a device that uses the elastic deformation of a spring or diaphragm that is calibrated to indicate the mechanical load applied to the specimen. A *Bourdon tube* is a coiled fluid-containing tube that straightens out as the internal pressure on the fluid is increased. The motion of the tube is used to rotate a pointer over a scale that is calibrated to read the hydraulic load applied to the specimen.

Tensile specimens are usually dog-bone shaped in that the central portion of the specimen is reduced in cross section compared with the two ends. This shape causes the test specimen to fail in the narrower central portion rather than at the ends, where the gripping devices affect the stress configuration.

Tensile specimens have a round cross section (round specimen) or a rectangular cross section (rectangular specimen). In general, tensile specimens obtained from welded joints are rectangular, unless taken from locations where it is not possible to obtain a specimen with a rectangular cross section, such as when testing filler metals.

The shape of the ends of the specimen is determined by the specimen gripping device that is used. The ends of round specimens are either plain, shouldered, or threaded. Rectangular specimens are generally made with plain ends, but occasionally pin ends are used. A *pin end* is a rectangular specimen that contains a hole for a pin bearing. See Figure 31-3.

The tensile test procedure consists of fixing the specimen firmly in the grips of the testing machine. An extensometer, which is a device for

Tensile specimens obtained from welded joints are typically rectangular, unless taken from a location where it is not possible to obtain a sample of rectangular cross section.

measuring the extension or elongation of the test specimen, is fitted to the specimen across its gauge length. See Figure 31-4.

The specimen is stretched to failure at some steady rate. Unless otherwise specified, the rate of straining is between .05″ and .5″ per min. Differences in the rate of straining could result in testing inconsistencies. Tensile test procedure is described in ASTM E 8, *Tensile Testing of Metallic Materials.*

As the test specimen is stretched, a load-extension (stress-strain) curve is plotted; the extensometer is removed before the specimen breaks. See Figure 31-5.

The load-extension curve shows load and extension limits for metals. Point A is the proportional limit.

The *proportional limit* is the maximum stress at which stress is directly proportional to strain. Between points A and B, the line starts to curve. Up to point B, the tensile specimen will return to its original length if the load is removed. Point B is the elastic limit.

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Figure 31-4. *An extensometer measures the extension or elongation of the tension test specimen.*

The tensile strength of metals is typically high, with tensile strengths of 60,000 psi or 70,000 psi common. A large machine would be needed to test a full-size part; so small test specimens are tested instead. A section is cut and tested, and the result is multiplied by a size ratio to find the tensile strength equivalent.

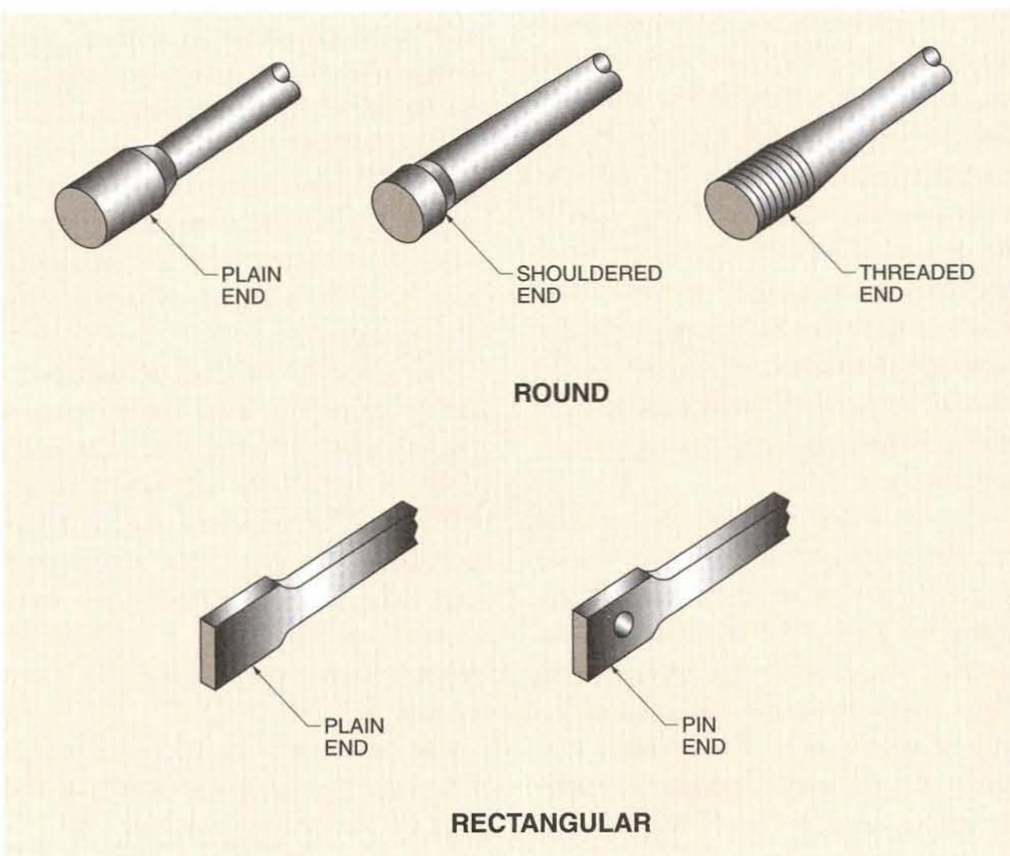


Figure 31-3. *A variety of tensile test specimen ends may be used to ensure that the testing machine securely and uniformly grips the test sample.*

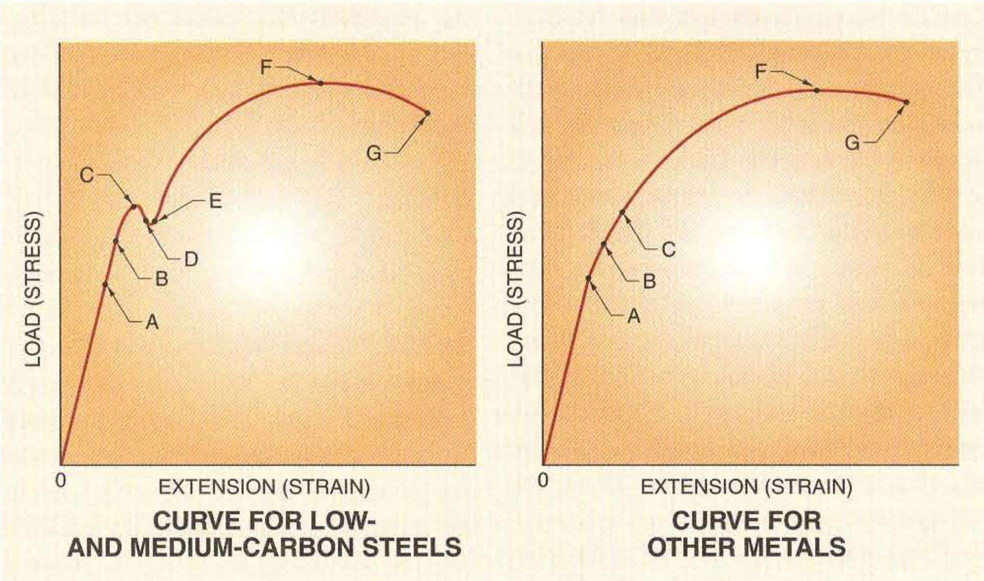


Figure 31-5. *The load-extension curve shows the load and extension limits for metals.*

Elastic limit is the maximum stress to which a material is subjected without any permanent strain remaining after stress is completely removed. Beyond point B, strain is permanent, or the strain in the specimen is plastic. *Plastic strain* is strain that remains permanent after the stress is removed. Beyond point B, the shape of the curve varies for different metals.

Low- and medium-carbon steels show a jog in their curve, which peaks at point C, or the yield point. *Yield point* is the location on the stress-strain curve where an increase in strain occurs without an increase in stress. Yield point behavior leads to Luders bands (ripples) on the test specimen. Stretcher strains (elongated markings) are observed in low-carbon steel pressings when deformed to the yield point. Yield point behavior is only exhibited by low- and medium-carbon steels.

Between points C and D the curve falls, indicating a plastic strain. The curve continues down to point E, the lower yield point. The curve eventually regains its upward movement and peaks at point F. Point F is the ultimate tensile strength. *Ultimate tensile strength* is a measure of the maximum stress (load) that a metal can withstand. Between points F and G, the specimen begins to neck down or develop a pronounced waist. Point G is the point of failure, the point at which fracture occurs. With all materials, the slope of the load-extension curve decreases and peaks at point F, with failure occurring at point G. With brittle metals, fracture may occur while the load is increasing toward point F.

When the tensile test is completed, the broken specimen is removed from the testing machine. The percent of elongation can be found by fitting the broken ends of the two pieces together and measuring the new gauge length. The new, increased gauge length and the reduced diameter at the narrowest point are measured. Measurement can be made on either side of the break. See Figure 31-6.

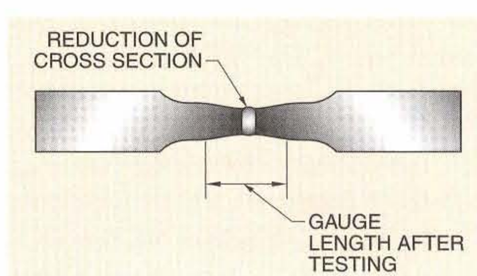


Figure 31-6. *The increased gauge length and reduced diameter at the narrowest point are measured and used to calculate the percent of elongation and the percent of reduction in area.*

Tensile Strength Measurement. The actual tensile strength is found by dividing the maximum load needed to break the piece by the cross-sectional area of the specimen. The cross-sectional area is determined by multiplying the width of the bar by its thickness. Tensile strength is an imprecise value because the original cross-sectional area is not the same as the reduced cross-sectional area that actually exists at the maximum load. Tensile strength is measured in thousands of pounds per square inch (ksi) or megapascals (MPa).

The standard ½″ diameter tensile specimen is referred to as a "505" because a diameter of .505″ has an area of .2″. To permit easy calculation of stress from loads, specimen diameters of .505″, .357″, .252″, .160″, and .13″ are convenient because computing of stress or strength may be done using the multiplying factors 5, 10, 20, 50, and 100, respectively. For rectangular specimens the cross-sectional area is calculated from the product of the width and thickness of the specimen.

The manufacturer of a base metal typically performs tensile testing and reports the results.

Percent Elongation and Percent Reduction Measurement. Percent elongation and percent reduction of area are measures of the ductility of a tensile specimen. Measurements are used to calculate the percentage of elongation and reduction in area of a material. They indicate the amount of plastic deformation prior to fracture of the test specimen. To find percent elongation of a tensile test specimen, apply the formula:

$$\%E = \frac{Lf - Lg}{Lg} \times 100$$

where

$\%E$ = percent elongation

Lf = final length

Lg = gauge length

100 = constant

For example, what is the percent elongation of a tensile specimen that has an initial gauge length of 2″ and a final length of 2.45″?

$$\%E = \frac{2.45 - 2}{2} \times 100$$

$$\%E = \frac{.45}{2} \times 100$$

$$\%E = .225 \times 100 = 22.5$$

$$\%E = \mathbf{22.5\%}$$

Percent elongation is calculated from the gauge length. The longer the gauge length, the less the effect necking down of the specimen has on final length, resulting in lower a percent elongation. When the gauge length is made equal to $k\sqrt{A}$, where k is a constant equal to 4.47 and A is equal to the cross-sectional area of the specimen, the percent elongation value remains practically constant for different gauge lengths. The most common gauge length in tensile testing is 2″. To find percent reduction of area of a tensile specimen, apply the formula:

$$\%RA = \frac{Do - Df}{Do} \times 100$$

where

$\%RA$ = percent reduction of area

Do = original diameter

Df = final diameter

100 = constant

For example, what is the percent reduction of area of a tensile specimen with an original diameter of .505″ and a reduced diameter of .350″?

$$\%RA = \frac{.505 - .350}{.505} \times 100$$

$$\%RA = \frac{.155}{.505} \times 100$$

$$\%RA = .307 \times 100$$

$$\%RA = \mathbf{30.7\%}$$

Round tensile specimens must be used to calculate percent reduction of area. Rectangular specimens have significant rounding of their corners during the test, making measurement of the cross-sectional area less accurate.

Failure location is the region of the specimen at which final failure occurs. Failure location is categorized as base metal, heat-affected zone (HAZ), or weld. Failure location is recorded on the PQR. Fabrication codes and standards usually require that failure location be in the base metal and not in the HAZ or in the weld. Percent elongation and percent reduction in area values are not usually provided for routine weld testing because the bend test is most often used to indicate ductility.

Shear Test

A shear test is used to determine the shear strength of fillet welds, brazed joints, and spot welds. Shear occurs when some force causes a material to separate, parallel to the load. An acceptable shear strength is usually at least 60% of the minimum specified tensile strength of the base metal. A shear test specimen is prepared to prevent it from rotating during the test. If the specimen were to rotate, interference from other types of stresses would be introduced into the test.

A *fillet weld shear test* is a shear test in which a tensile load is placed on a fillet weld specimen so that the load shears the fillet weld in a longitudinal or a transverse direction. The longitudinal test measures the longitudinal shear strength of the specimen for loads parallel to the axis of the weld. The transverse test measures the transverse shear strength of the specimen for loads normal to the axis of the weld. To prevent rotation and bending stresses during testing, transverse shear specimens are tested as double lap joints. The two shear test types are tension shear test and peel test.

Refer to AWS C1.1 and AWS C1.1M, Recommended Practices for Resistance Welding, *for shear test specimen dimensions, test fixtures, and evaluation methods.*

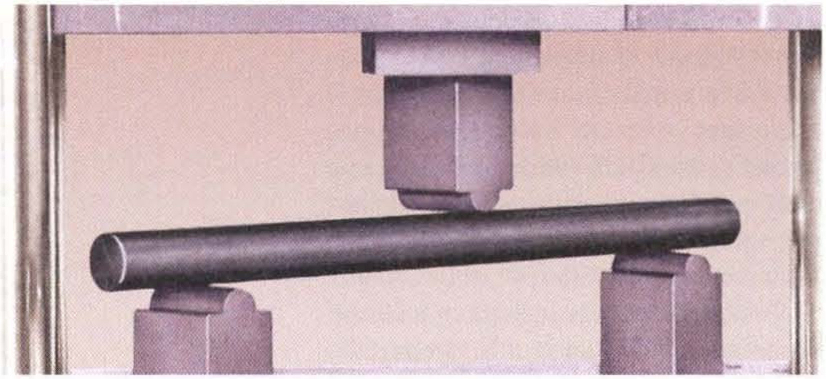
Tension Shear Test. A *tension shear test* is a shear test in which a prepared specimen is pulled to failure in a tensile testing machine. Specimens can be pulled from fillet welded, brazed, or spot-welded assemblies. The shear strength of the material is calculated from the load at failure.

To check the shear strength of a transverse weld, a specimen is prepared, placed in a tensile testing machine, and pulled until it breaks. Dividing the maximum load in pounds by twice the width of the specimen will indicate the shearing strength in pounds per linear inch. If the shearing strength in pounds per square inch (psi) is desired, the shearing strength in pounds per linear inch is divided by the throat dimension of the weld.

The types of tension shear test are the brazed joint tension shear test and the spot-weld tension shear test.

The *brazed joint tension shear test* is a shear test that determines the strength of filler metal in a brazed joint. The specimen is composed of two single ⅛″ thick sheets joined by brazing with a filler metal. The parts should be fixtured during brazing to maintain accurate specimen alignment. The shear strength of the filler metal is calculated from the tensile load at failure divided by the brazed area.

The *spot-weld tension shear test* is a shear test that determines the strength of arc welds and resistance spot welds. The specimen is made by overlapping materials of suitable size and creating an arc or resistance spot weld in the center of the overlapped area. The load on the weld causes bending and rotation of the weld, resulting in failure around the edges of sheet thicknesses less than about .040″. On thicker sheets, the base metal resists bending and the spot will fail at or near the weld. With specimen thicknesses of .19″ or larger, the grips of the test machine are offset to reduce loading on the weld.



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Bend test specimens allow inspection of all sides of a weld joint to determine the ductility and plastic deformation capabilities of a weld.

Peel Test. A *peel test* is a shear test in which a specimen is gripped in a vise and then bent and peeled apart with pincers to reveal the weld. The peel test is an inexpensive alternative to the spot-weld tension shear test. The weld size is measured and compared to that required for the joint. If the weld size is equal to or exceeds the standard size for the design, the production weld is acceptable. The peel test may not be suitable for high-strength base metal or for thick sheets of metal. See Figure 31-7.

Bend testing is an economical way of judging weld quality to qualify a procedure or welder.

Bend Test

A *bend test* is a destructive test used to determine the ductility of a weld by bending a welded specimen around a standardized mandrel. Bend tests provide qualitative information for a specific procedure qualification record (PQR) on the acceptability of a weld. Bend tests are also used for welder performance qualification (WPQ).

Bend tests provide information on the plastic deformation capability of a welded joint. The plastic deformation capability is shown through the ability of the weld to resist tearing. The weld orientation and the bend location must be specified for bend tests.

A bend test may also reveal discontinuities on the surface and can be used to expose incomplete fusion and delamination. Fabrication codes and standards specify the maximum allowable size for discontinuities in welding procedure qualification or welder performance qualification bend tests. The most common bend test used for groove welds is the guided bend test.

Peel Test
Figure 31-7

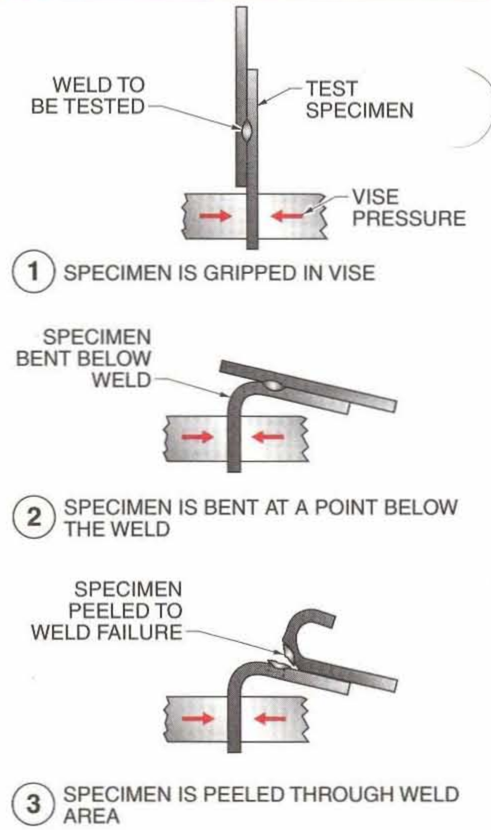


Figure 31-7. *A peel test is an inexpensive alternative production control tool for testing shear strength in a weld joint.*

Guided Bend Test. A *guided bend test* is a bend test in which a rectangular piece of welded metal is bent around a U-shaped die and forced into a U shape. The weld and the HAZ must be completely within the bent portion of the specimen after testing. The guided bend test is the most commonly used ductility test for groove welds, surfacing welds, and fillet welds.

Guided bend test fixtures can be bottom guided or bottom ejecting. The bottom guided bend fixture is designed to support the specimen in the die as it is bent. The bottom ejecting guided bend fixture allows the specimen to be

ejected from the die after it is bent. Both types of testing are described in ASTM E 190, *Method for Guided Bend Test for Ductility of Welds.* See Figure 31-8.

Two specimens must be used for the guided bend test. A face-bend specimen is used to check the quality of fusion, or whether the weld is free of defects such as porosity and inclusions. A root-bend specimen is used to check the degree of weld penetration. See Figure 31-9.

To perform a face-bend test, the test specimen is placed in a test jig with the weld face down and forced by a plunger into a U-shaped die. The specimen is substantially bent through 180°, but when it is removed from the die the specimen will spring back slightly and no longer exhibit a perfect 180° bend. The specimen is removed and evaluated. If upon examination cracks greater than 1/8″ appear in any direction, the weld is considered to have failed. The localized overstrain on the convex side of the U-shaped bend reveals the presence of weld defects such as lack of fusion. The convex side of the specimen is inspected for slag inclusions, porosity, and cracks. If these exceed the requirements of the applicable fabrication code or standard, the weld must be rejected.

In a root-bend test, the test specimen is placed in a jig with the root down, or in the reverse position of the face-bend piece. To be an acceptable weld, the specimen must show no cracks.

When preparing guided bend test coupons, grinding and polishing may make it hard to distinguish the location of the weld. An acid etch may be needed to locate the weld area.

The guided bend test is the most commonly used ductility test for groove welds, surfacing welds, and fillet welds.

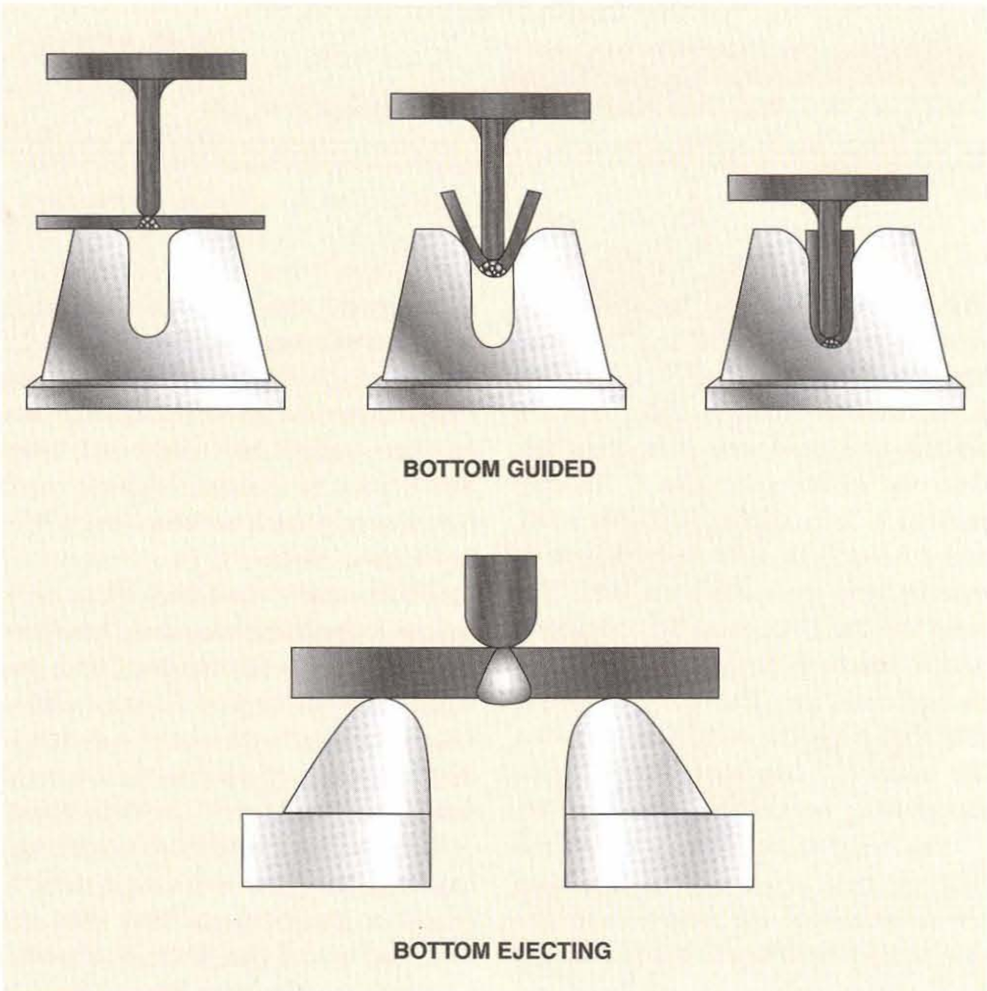
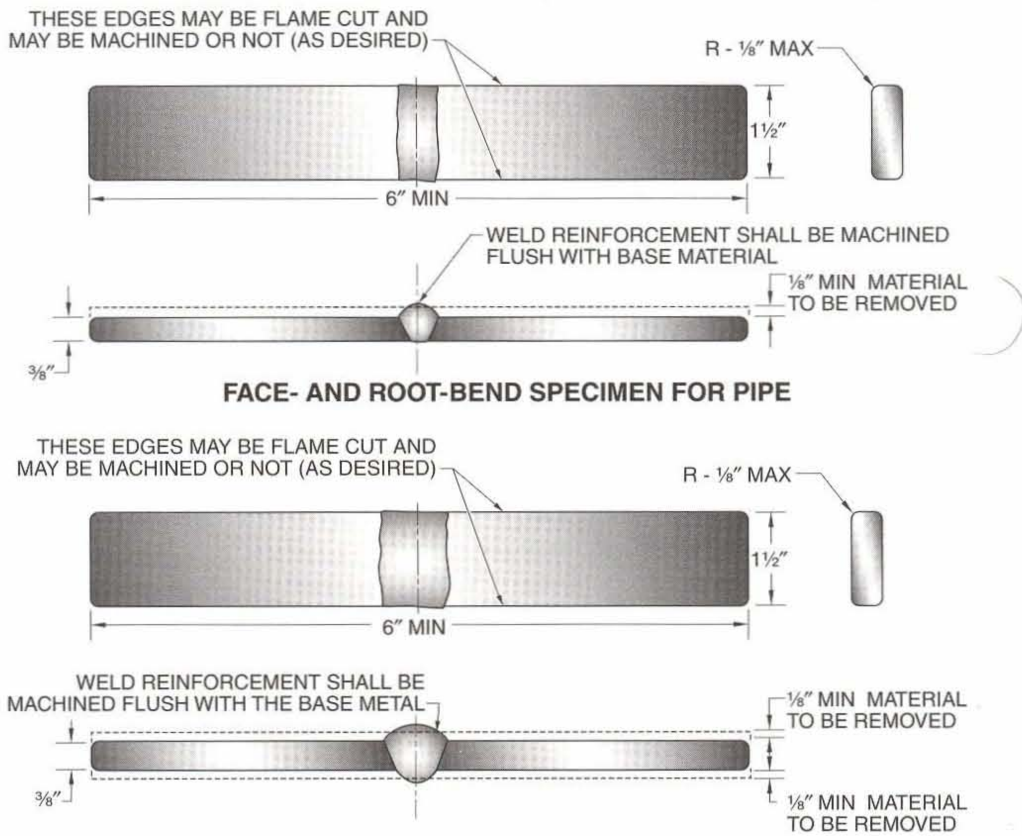


Figure 31-8. *Guided bend test fixtures may be bottom guided or bottom ejecting.*

Figure 31-9. *Face-bend and root-bend specimens are specified for pipe and plate. Face-bend specimens check the quality of fusion and root-bend specimens check the degree of weld penetration.*

Guided Bend Test Specimens
Figure 31-9



Wraparound Guided Bend Test. A *wraparound guided bend test* is a bend test in which a specimen is bent around a stationary mandrel a specified amount to expose weld discontinuities. One end of the specimen is fixed to prevent it from sliding during bending and a roller is used to force the specimen to bend around the mandrel. The weld and the HAZ must be completely within the bent portion of the specimen after testing. The test specimen is removed from the bend fixture when the outer roll has moved 180° from the starting point. See Figure 31-10.

The bend location may be on the face, the root, or the side. A face-bend test is made with the weld face in tension. A root-bend test is made with the weld root in tension. A side-bend test is made with the weld cross section in tension. Side-bend tests are useful for exposing discontinuities near the mid-thickness of the weld that might not be seen in face- or root-bend tests. Side-bend specimens are normally used for relatively thick sections (over ⅜″). See Figure 31-11.

Transverse face-bend specimens have a longitudinal axis that is perpendicular to the weld and bent with the weld face in tension. Longitudinal face-bend specimens have a longitudinal axis that is parallel to the weld and bent with the weld face in tension.

Transverse root-bend specimens have a longitudinal axis that is perpendicular to the weld and bent with the root surface of the weld in tension. Longitudinal root-bend specimens have

Wraparound Guided Bend Test
Figure 31-10

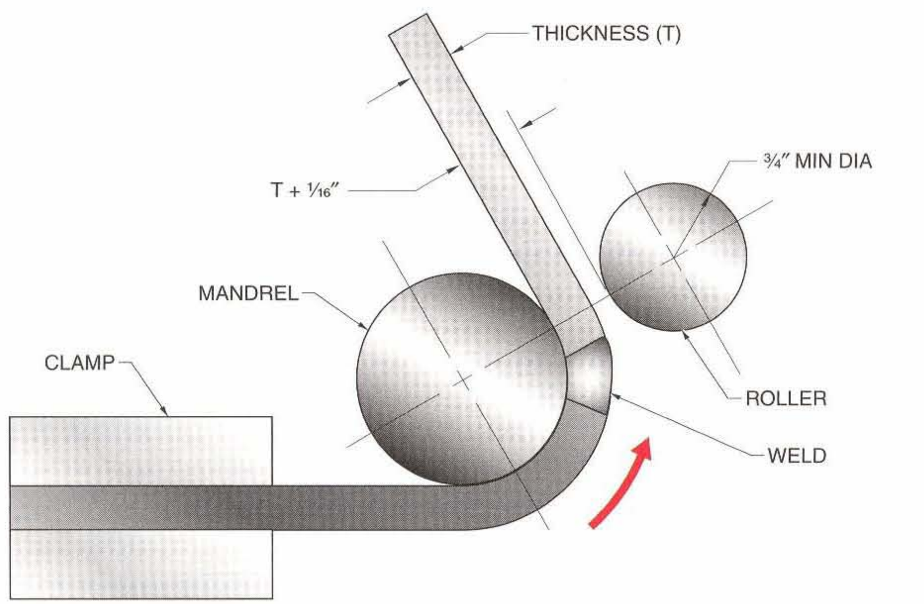


Figure 31-10. *A wraparound guided bend test uses a roller to ensure that the specimen bends to the correct radius around the mandrel.*

a longitudinal axis that is parallel to the weld and bent with the root surface of the weld in tension.

Transverse side-bend specimens have a longitudinal axis that is perpendicular to the weld and is bent with the surface that shows the most significant discontinuities in tension. Transverse side-bend specimens are used for plate or pipe that is too thick for a face-bend or root-bend specimen and are recommended for welds with a narrow fusion zone. If the thickness of single- or double-groove joints is more than 1½″, the specimen may be cut into equal strips between ¾″ and 1½″ wide, which are then bent to the required radius determined in the bend test.

The length of a surfacing weld specimen is perpendicular to the weld direction for transverse bend specimens and parallel to the weld direction for longitudinal bend specimens. A minimal amount of surfacing weld is removed from the face-bend specimen surface to obtain a smooth surface. The minimum thickness of surfacing after finishing is ⅛″.

Bend Locations
Figure 31-11

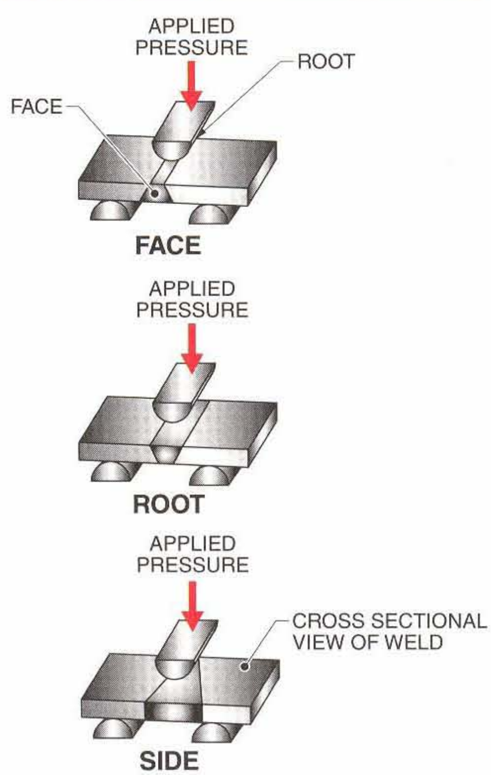


Figure 31-11. *The bend location in a guided bend test may be on the face, the root, or the side of the specimen.*

The specimen thickness and bend radius are chosen according to the ductility of the metal being tested. Most qualification tests of low-carbon steel require that the specimen be bent around a mandrel having a diameter four times the thickness of the specimen.

Calculation of strain in the guided bend test or wraparound bend test on the outside surface of a bend specimen is given, approximately, by the following formula:

$$e = \frac{100t}{2R + t}$$

where

e = strain, in percent

t = bend test specimen thickness, in in.

r = inside bend radius, in in.

For example, what is the percent strain when a ⅜″ (.375) specimen is bent around a 1.5″ diameter mandrel using a guided bend test?

$$e = \frac{100(.375)}{2(1.5) + .375}$$

$$e = \frac{37.5}{2(1.5) + .375}$$

$$e = \frac{37.5}{3 + .375}$$

$$e = \frac{37.5}{3.375}$$

$$e = \mathbf{11\%}$$

Low-carbon steel welds can easily achieve the 11% strain value. However, if weld defects are present, the bend test specimens will consistently fail.

When the deposited weld metal is stronger than the base metal, bending will begin in the base metal, resulting in more bending there and little, if any, bending in the weld metal. In this situation the severest test region is the fusion zone between the weld and the base metal.

When the deposited weld metal is weaker than the base metal, bending begins in the weld, resulting in more bending in the weld than in the base metal. A more severe test of the weld results, and failure may occur because the weld metal ductility is exceeded and not because of a defect in the weld. See Figure 31-12.

When testing welds in dissimilar strength metals, such as medium-carbon steel or low-carbon steel, the unequal strength capabilities of the metals may cause the specimen to slide sideways in the guided bend test fixture.

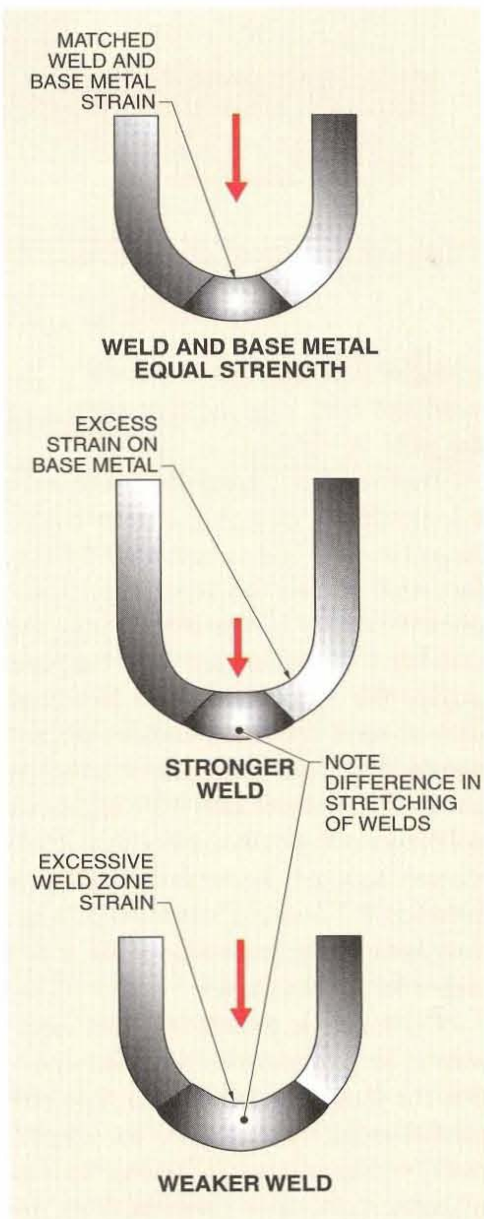


Figure 31-12. *Problems associated with the guided bend test relate to the relative strengths of the weld and base metal, and the applied loads during testing.*

Hardness Test

The hardness of a material is its resistance to deformation (particularly permanent deformation), indentation, or scratching. A *hardness test* is a destructive test used to determine the relative hardness of the weld area as compared with the base metal. See Figure 31-13.

Hardness Tester
Figure 31-13

Buehler Ltd

Figure 31-13. *A hardness test is performed using a hardness tester, such as a microhardness tester, to determine the relative hardness of the weld area as compared with the base metal.*

Hardness testing is sometimes used instead of the more expensive tensile testing methods in heat-treating operations since comparable results can be obtained. Hardness tests are a widely used quality control tool in metal processing operations such as heat treatment because they are sensitive, rapid, and relatively nondestructive. Hardness tests are less commonly used for welds because the critical area for hardness testing, the HAZ, requires special preparation. Additionally, hardness testing does not provide adequate information on the physical quality of the weld compared with other tests such as the guided bend test. Hardness is indicated by values obtained from various hardness testing machines.

Hardness testing can provide information on metallurgical changes caused by welding. In alloy steels or medium-carbon steels, a high hardness value in the HAZ might indicate insufficient preheating or postheating. Welding may significantly reduce the HAZ hardness in cold-worked or age-hardened alloys by annealing or over-aging, respectively, which reduces the overall strength of the joint. Indentation hardness testing is most often applied to weld testing and uses the surface impression produced by a standardized-shape indenter and standardized load to determine hardness. The depth or size of the impression is measured to obtain the hardness value for the test specimen.

Indentation hardness tests for welds consist of Brinell, Rockwell, and Vickers tests, which provide information on the bulk properties of the metal, and microhardness tests, which provide information on the weld and the HAZ in the metal. Converting hardness numbers between different tests must be done carefully.

Brinell Hardness Test. The *Brinell hardness test* is an indentation hardness test that uses a machine to press a 10 mm diameter, hardened steel ball into the surface of a test specimen. The Brinell hardness test is used to determine base metal hardness. The load must remain on the specimen 15 sec for ferrous materials and 30 sec for nonferrous materials. Sufficient time is required for adequate flow of the material being tested; otherwise the readings will be in error. See Figure 31-14.

Hardness testing, although considered destructive, does not necessarily require that the specimen be cut into pieces, and is thus convenient and relatively rapid.

Hardness is calculated by dividing the load by the area of the curved surface of the indentation. The Brinell hardness number is found by measuring the diameter of the indentation and then finding the corresponding hardness number on a calibrated chart. The test is described in ASTM E 10, *Brinell Hardness Testing of Metallic Materials.*

Brinell Hardness Test
Figure 31-14

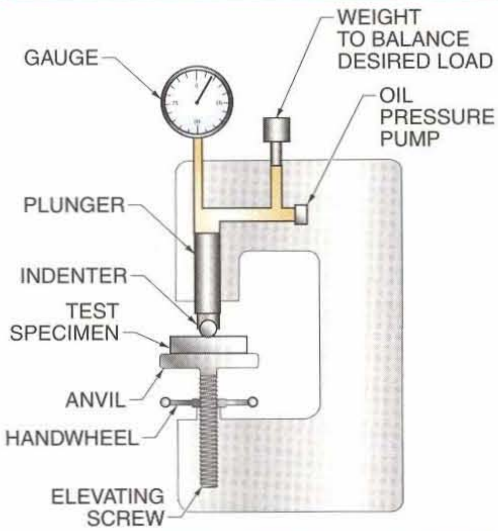


Figure 31-14. *A Brinell hardness test applies a load for a specific period and causes an indentation in the metal that is used to calculate hardness.*

The Brinell hardness number followed by the abbreviation HB indicates a hardness value made under standard conditions using a 10 mm diameter hardened steel ball, a 3000 kg load, and an indentation time of 15 sec to 30 sec. However, the load applied to the steel ball depends on the type of metal under test. A 500 kg steel ball is used for aluminum castings and a 3000 kg steel ball is used for ferrous metals. The diameter of the indentation is measured to .05 mm using a low-magnification portable microscope. Care must be taken to measure the exact diameter of the indentation and not the apparent diameter caused by edge effects that result in a ridge or depression encircling the true indentation. See Figure 31-15.

A code is used when other test conditions are required. For example, 75 HB 10/500/30 indicates a Brinell hardness number of 75 obtained in a test using a 10 mm diameter hardened steel ball with a 500 kg load applied for 30 seconds. For extremely hard metals, a tungsten carbide ball is substituted for the steel ball, allowing readings as high as 650 HB.

The Brinell ball makes the deepest and widest indentation of any hardness test, so that it indicates an average hardness value over many grains of the metal. Consequently, the Brinell hardness test is the least affected by surface irregularity or inhomogeneity. Sometimes it is necessary to grind a flat spot on the surface to improve the diametrical measurement. The Brinell test is not suitable for very thin, case-hardened, or hard-faced components.

Brinell Test Indentations
Figure 31-15

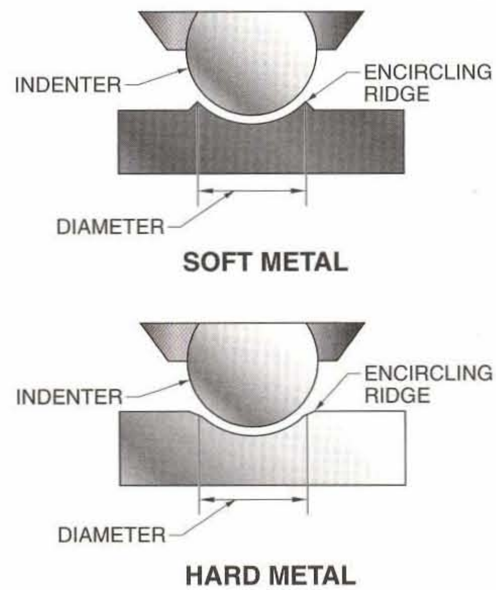


Figure 31-15. *Careful measurement must be taken after a Brinell hardness test to accurately determine the size of indentations in soft and hard metals.*

Rockwell Hardness Test. The *Rockwell hardness test* is an indentation hardness test that uses two loads, supplied sequentially, to form an indentation on a metal test specimen to determine hardness. The Rockwell hardness test is the most commonly used and versatile hardness test. The Rockwell hardness test is commonly used for weld and base metal measurement. The Rockwell testing machine has a variety of attachments that enable it to measure the hardness of a wide range of materials.

A 1⁄16″ diameter steel ball and a 120-diamond cone are the two types of indenters. A minor load of 10 kg is applied that helps seat the indenter and remove the effect of surface irregularities. A major load, which varies from 60 kg to 150 kg, is then applied. See Figure 31-16.

The amount of the major load determines the type of indenter used. For example, a steel ball is used with the 60 kg load and a diamond cone with the 150 kg load. The difference in depth of indentation between the major and minor loads provides the Rockwell hardness number. This number is taken directly from the dial on the machine. The Rockwell hardness test is described in ASTM E 18, *Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials.*

Several types of Rockwell hardness scales are used for measuring hardness. The designation system has a hardness number followed by HR, followed by another letter that indicates the specific Rockwell scale. The two most common scales are Rockwell B (HRB) and Rockwell C (HRC).

The Rockwell B scale uses a 1⁄16″ diameter steel ball and a 100 kg load for relatively soft materials. It is used on annealed low-carbon steel, which may exhibit a hardness of approximately 85 HRB.

The Rockwell C scale uses a diamond cone and a 150 kg load for relatively hard materials. For example, a quenched and tempered medium-carbon, low-alloy steel usually exhibits hardness between 30 HRC and 45 HRC, depending on the tempering temperature. See Appendix.

For Rockwell hardness testing, both sides of the test specimen must be clean, scale-free, dry, and parallel. Special jigs help support round or oversize test specimens to ensure immobility during the test.

Vickers Hardness Test. The *Vickers hardness test* is an indentation hardness test that uses an indenter with a 136° square-base diamond cone, and that may be used to test hardness in the base metal and weld metal. The applied load varies from 1 kg to 120 kg. The Vickers hardness number is determined from the load divided by the surface area of the indentation.

Rockwell Hardness Test
Figure 31-16

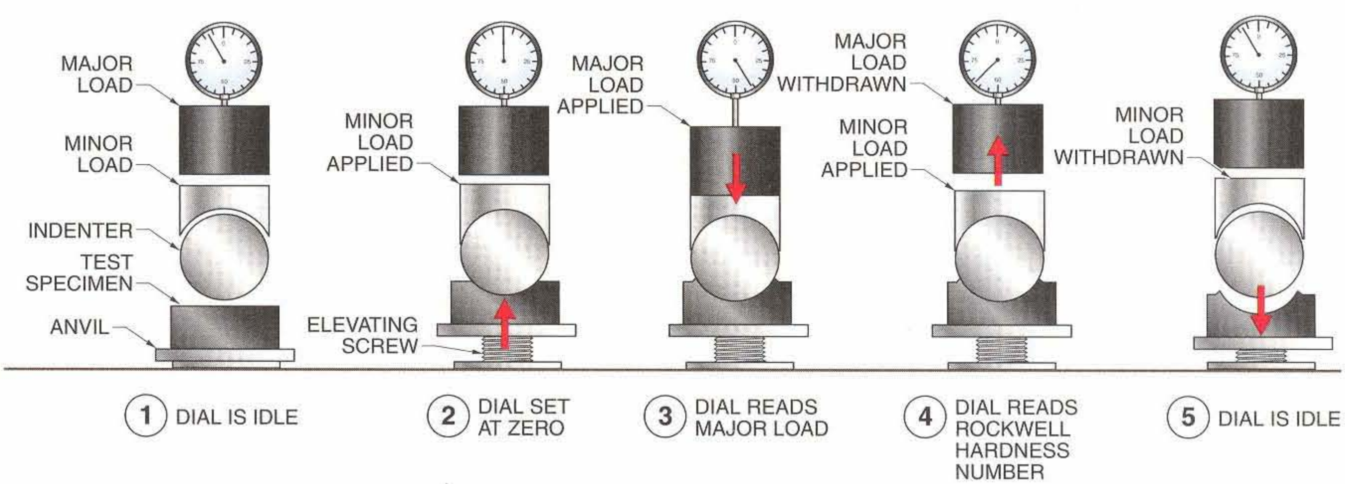


Figure 31-16. *The Rockwell hardness test uses two loads, a minor load and a major load, which are applied sequentially to determine hardness.*

To conduct a Vickers hardness test, the specimen is placed on an anvil and raised by a screw until it is close to the point of the indenter. The starting lever is tripped, allowing the load to be slowly applied to the indenter. The load is released, the anvil lowered, and a filar microscope is used to measure the diagonals of the square indentation to ±.001 mm. Diagonal measurements are averaged to obtain the Vickers hardness number, which is followed by the letters HV. The Vickers hardness test is described in ASTM E 92, *Vickers Hardness Testing of Metallic Materials.*

The Vickers hardness test allows extremely accurate readings to be taken. Additionally, one type of indenter covers all types of metals and surface treatments. However, test specimen preparation is critical because a poor surface finish makes the measurement of the diagonals extremely difficult. A fine emery finish is the coarsest face allowable.

Microhardness Test. A *microhardness test* is a type of indentation hardness test that uses light loads of less than 200g. Microhardness tests are at the opposite end of the scale to the Brinell or Rockwell hardness tests. A polished surface, coupled with the light loads, allows the hardness of individual grains of metal or other microconstituents to be measured.

To conduct a microhardness test, the test specimen is placed under the microscope of the microhardness tester. The area of interest is positioned at the intersection of the cross wires. The indenter is swung into place and the load applied for a set period. The load is then removed, the microscope swung back, and the length of the diagonals of the indentation measured. The microhardness reading is obtained from the measurements and from a chart. Microhardness testing is described in ASTM E 384, *Test Method for Microhardness of Metals.*

Microhardness testing of welds is usually done on ground and polished, or ground, polished, and etched cross sections of a weld. Measurements can be made in any specific area, but they are most frequently made as a series of regularly spaced indentations across the base metal, HAZ, and weld metal for single- or multiple-pass welds. The space between readings is usually between 1⁄16″ and 1⁄8″. See Figure 31-17.

Microhardness Test
Figure 31-17

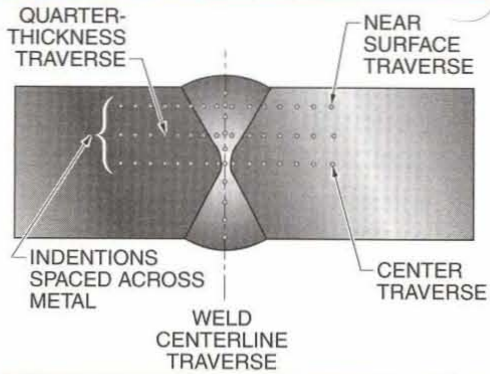


Figure 31-17. *Microhardness measurements are taken at regular intervals across a ground, polished, and etched cross section of a weld.*

Regular conversion between different hardness scales should be avoided unless there is a large amount of experience and data available to justify making such correlations. Indentation hardness readings are based on a combination of properties such as friction, elasticity, and viscosity of the indenter and the specimen. These vary with the type of specimen and test. The distribution of plastic strain in the test specimen, which is caused by the particular type of indenter, is also an important factor.

Separate conversion tables are required for different alloy families. ASTM E 140, *Standard Hardness Conversion Tables for Metals (Relationship between Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness, and Knoop Hardness),* contains hardness conversion tables for several major families of alloys. Pocket-size conversion charts supplied by vendors are usually an extract from the steels portion of ASTM E 140. See Appendix.

Toughness Tests

Toughness tests measure the ability of materials to absorb energy at high strain rates and deform plastically rather than fracture in a brittle manner, particularly in the presence of stress raisers such as cracks and notches. A *toughness test* is a dynamic test in which a specimen is broken by a single blow and the energy absorbed in breaking the piece is measured in foot-pounds (ft-lb). The purpose of the test is to compare the toughness of the weld metal with the base metal. It is especially significant in determining whether any of the mechanical properties of the base metal have been destroyed due to welding. Toughness of welds is an important property because structural metals must be able to deform and give warning of impending failure.

The mechanical properties of a metal are strongly affected by the rate of straining. A metal tested at a low strain rate may break with a large amount of strain (elongation), but a metal tested at a high strain rate may break with little or no elongation. The metal is tough and ductile at the low strain rate and is brittle at the high strain rate. See Figure 31-18.

Toughness is also affected by the test temperature and presence of stress raisers in the specimen. The toughness of certain metals decreases significantly below a characteristic temperature. Stress raisers in welds, such as a sharp change in weld profile at the surface or internal inclusions, may decrease toughness.

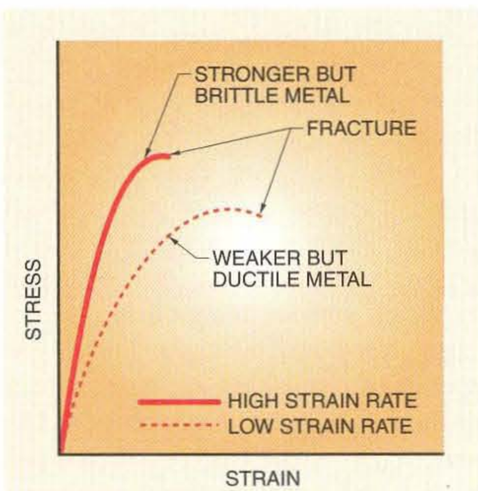


Figure 31-18. *Metal tested at a low strain rate is ductile compared with the same metal tested at a high strain rate.*

Toughness tests include the Charpy V-notch test, plane-strain fracture toughness test, and nil-ductility transition temperature test.

Toughness testing requirements depend on the specific applicable fabrication code or standard.

Charpy V-Notch Test. The *Charpy V-notch test* is a toughness test that uses the energy produced by a dynamic load, and measures the energy needed to break a small machine-notched test specimen. The Charpy specimen is a square-shaped bar containing a machined V-shaped notch. The purpose of the notch in the test specimen is to facilitate fracture in a controlled location. The resulting measurement is an indicator of toughness.

The Charpy V-notch test uses the energy produced by a dynamic load, and measures the energy needed to break a small machine-notched test specimen.

A Charpy V-notch test is performed in a universal pendulum impact tester. See Figure 31-19. The specimen is placed horizontally against the two supports at the bottom of the tester. The pendulum is raised to a standard height, giving it a potential energy of 240 ft-lb [325 joules (J)]. The pendulum is released and the specimen is struck and broken as the pendulum swings through its arc. The swing of the pendulum after it strikes the specimen indicates the energy absorbed on impact and is measured in foot-pounds or joules. When struck by the pendulum, tough materials absorb a significant amount of energy and brittle materials fracture with relatively little energy absorbed. Tough materials cause the pendulum to travel a shorter distance after striking the test specimen. With brittle materials, the pendulum travels a longer distance after impact.

ASTM 23, Notched Bar Impact Testing of Metallic Materials, *gives requirements for the Charpy V-notch test, which is the most common impact test used.*

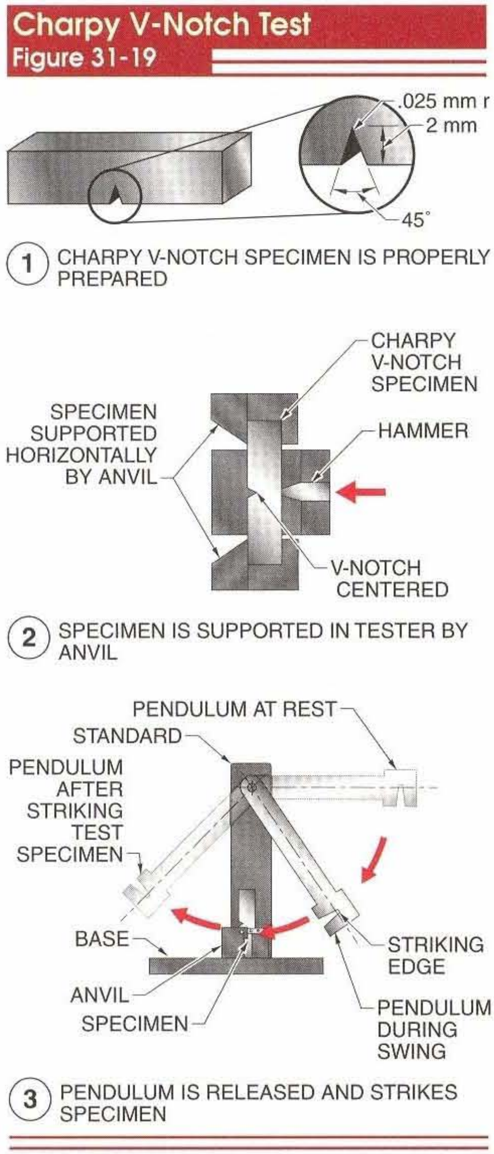


Figure 31-19. *The Charpy V-notch test requires very small specimens, allowing for multiple orientations of a test to be performed on a part. The swing of the pendulum after striking the specimen indicates the energy absorbed on impact.*

The Charpy V-notch test is widely used because it requires a small specimen size and it permits correlating the results of a large body of tests with service experience. The simple method of specimen support allows testing to be performed over a range of test temperatures. Specimens are heated in a furnace or cooled in a refrigerator to the test temperature, removed, and then rapidly tested with minimal temperature change.

The small specimen size required for the Charpy V-notch test is also convenient because specimens may be cut at various orientations or locations within a part. Since the properties of metals may vary according to orientation or location, in quality control programs it is often necessary to check for properties in orientations that would exhibit the lowest toughness. For example, with plate products, a test specimen with a transverse orientation usually exhibits lower quality, or lower mechanical properties. With welds, specimens that have notch locations in the weld metal, HAZ, or base metal may exhibit significantly different notch toughness values. See Figure 31-20.

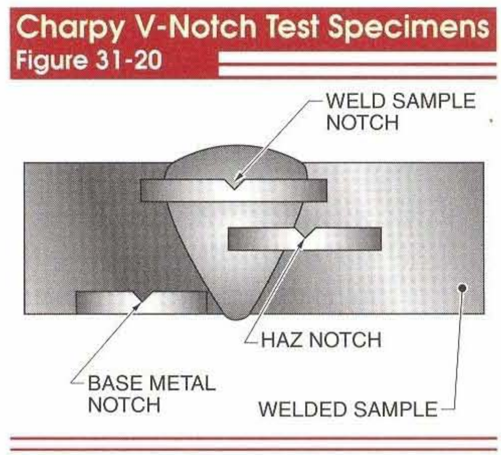


Figure 31-20. *Charpy V-notch test specimens machined from different locations in a weld may exhibit different notch toughness values.*

The behavior of metals in Charpy V-notch testing is dependent on the rate of loading, test temperature, and type of notch. These variables make it difficult to translate the absorbed energy values into design criteria. Nevertheless, the long history of Charpy V-notch testing allows acceptance or rejection limits to be placed on large quantities of materials. For example, some specifications require a minimum Charpy V-notch requirement for steel products of 15 ft-lb at the minimum expected service temperature. However, this does not mean that a test specimen exhibiting 60 ft-lb is four times tougher than the minimum. The main value of the Charpy V-notch test is as a criterion of acceptance of material when reliable service behavior has been established.

Notch toughness testing requirements depend on the specific fabrication code or standard. When applicable in the ASME Boiler and Pressure Vessel Code, they are known as supplementary essential variables. For example, notch toughness testing may be required for carbon and low-alloy steel equipment subject to cooling in service, such as through operation upsets or auto-refrigeration. *Auto-refrigeration* is cooling that occurs when gas expands, as in the sudden release of gas from a pipe or piece of equipment. Materials whose properties are enhanced by heat treatment may also require notch toughness testing.

Notch toughness values may be altered with an increase in heat input during welding. Conditions that may contribute to higher heat input include higher welding heat input; higher maximum interpass temperature; longer postheat time at temperature; reduction in base metal thickness; change to an uphill progression in vertical welding; change from stringer bead to weave bead welding; and the physical location of specimens taken from some pipe test samples. A welding procedure specification must be established that accounts for these variables to ensure that the notch toughness properties of the weld metal and HAZ are not reduced.

Plane-Strain Fracture Toughness Test. The *plane-strain fracture toughness test* is a toughness test that measures the resistance of metals to brittle fracture propagation in the presence of stress raisers such as weld defects. High stress concentrations may occur at the tips of internal discontinuities (such as lack of fusion) in some metals and produce a running (brittle) crack.

The fracture toughness of a metal at a given temperature is proportional to the stress level, measured in thousand pounds per square inch (ksi) or megapascals (MPa), and the square root of the crack length, measured in inches or meters. The unit of measure for fracture toughness is $\text{ksi}\sqrt{\text{in.}}$ (ksi root inch). Plane-strain fracture toughness test data are used in the design of structures, as when determining the allowable internal size of a discontinuity that might lead to a catastrophic failure.

Various types and sizes of specimens are used in the plane-strain fracture toughness test. A compact tension specimen is a block containing a machined notch that is placed in a fatigue-testing machine to produce a small fatigue crack at the root of the machined notch. The tip of the fatigue crack extending from the root of the machined notch is a localized region of high stress intensity.

The test specimen is pulled to failure in a testing machine and the load is plotted against the opening of the notch. The load and crack extension at the sudden failure of the test specimen are measured and used to calculate the fracture toughness of the material. The test method is described in ASTM E 399, *Plane-Strain Fracture Toughness Testing of Metallic Materials*. Fracture toughness testing is used to determine the critical stress intensity, which is a measure of the resistance of a metal to brittle fracture propagation in the presence of flaws and cracks. Pressure vessels, storage tanks, airplanes, and ships are examples of structures that are designed and manufactured in accordance with fracture toughness principles.

Nil Ductility Transition Temperature Test. The *nil ductility transition (NDT) temperature test* is a toughness test that measures the temperature at which the fracture behavior of a metal changes from ductile to brittle in the presence of a stress raiser. This temperature is sometimes referred to as the ductile-to-brittle transition temperature (DBTT). Some metals, especially carbon and low-alloy steels, show a sharp transition in toughness when temperature decreases.

The change in toughness capability may be the controlling factor in determining a metal's serviceability. Carbon steels lose ductility below a certain temperature, leading to brittleness. Large steel storage tanks have failed catastrophically in cold weather because the NDT temperature of the plate material was higher than the atmospheric temperature at the time of failure.

The Charpy V-notch test and the drop weight test are used to determine the NDT temperature. The Charpy V-notch test determines the NDT temperature by testing specimens over a range of temperatures. The results are plotted as impact strength against test temperature.

The drop weight test is a more reliable method than the Charpy V-notch test for measuring NDT. The specimen is a slab or plate that is up to ⅝″ thick. A weld bead made from a brittle alloy is laid down the center of the plate. The plate is brought to the test temperature and placed in the test fixture. It is supported along both ends parallel to the weld, with the weld side facing down. A weight located vertically above the center of the plate is allowed to drop, causing the plate to bend.

Break tests are also rapid methods of assessing weld quality and may be called out by specific industries.

Tinius Olsen Testing Machine Co., Inc.

Electromechanical tensile testing machines can be used to perform tension, compression, and flex tests on a specimen.

Cracking of the weld bead is initiated at 3° of bend. After that point the weld bead continues to crack, which initiates a fracture in the plate. To ensure the strain induced in the plate is elastic, a stop is placed below the weld bead. The stop limits the amount of deflection of the plate to 5° of bend. See Figure 31-21.

If the temperature of the plate is below the NDT temperature, the crack runs and the plate breaks in two. At any temperature above the NDT temperature, the crack stops before it spreads through the plate. The NDT temperature is the lowest temperature at which the plate will not break in two. The drop weight test is described in ASTM E 208, *Drop Weight Test to Determine Nil Ductility Transition Temperature of Ferritic Steels.*

Drop Weight Test
Figure 31-21

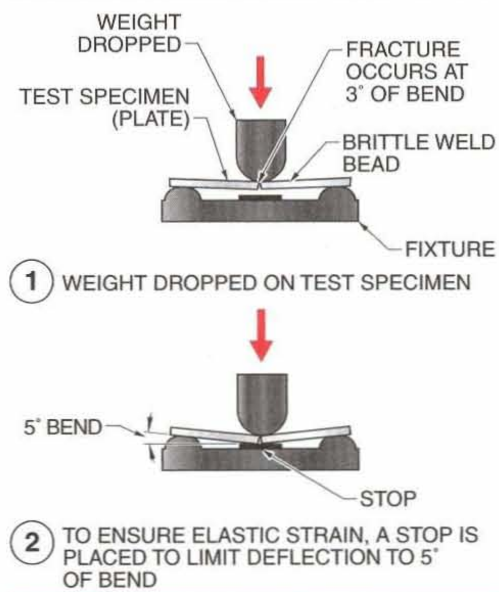


Figure 31-21. *The drop weight test is a reliable indicator for measuring NDT temperature.*

Break Tests

Break tests are a rapid and convenient method of evaluating certain types of welds and are used for welder qualification. Break tests include the nick-break test and the fillet weld break test.

Nick-Break Test. The nick-break test is conducted by saw cutting a small notch in a weld assembly or specimen, followed by breaking it with hammer blows, stretching, or bending. A test specimen is prepared and placed on supporting members. A load is applied to the specimen until it breaks. The surface of the fracture is then examined for defects such as porosity, slag inclusions, overlaps, etc. See Figure 31-22.

For a more accurate check of the weld, the fractured pieces should be subjected to an etch test. The nick-break test is used primarily in the pipeline industry, as described in American Petroleum Institute (API) standards such as API Standard 1104, *Standard for Welding Pipeline and Related Facilities.* The nick-break test may also be used to evaluate fusion welds, flash butt welds, pressure welds, or friction welds in pipe or plate.

Nick-Break Test
Figure 31-22

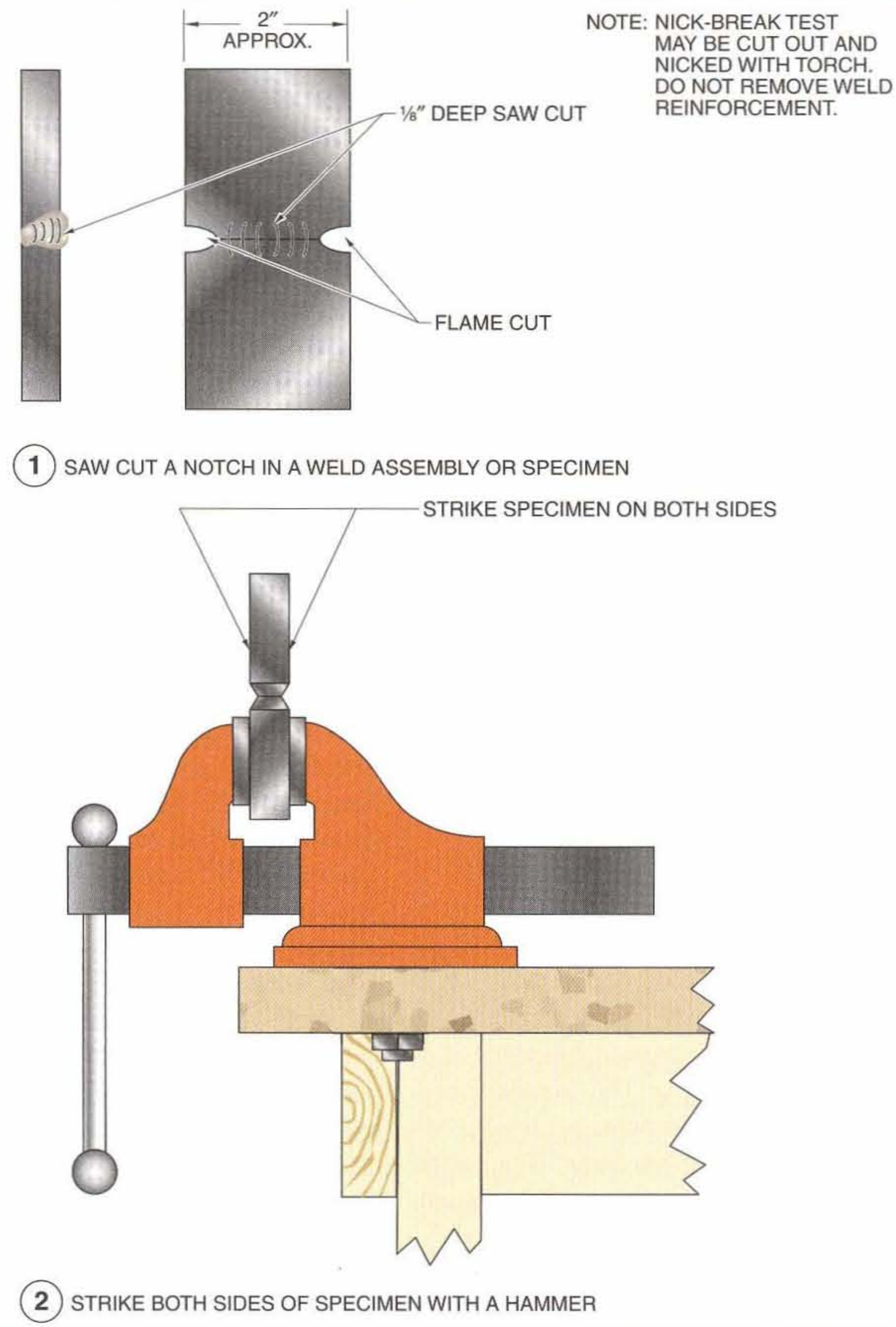


Figure 31-22. *A nick-break test consists of notching a welded specimen and fracturing it with hammer blows.*

Specimens for nick-break testing are either a full-size welded piece or a specimen cut from a full-size piece. The weld region is notched and then firmly supported at one or both ends. Once the specimen is supported, it is fractured by a hammer blow. One side is hit twice and then the specimen is turned 180° and the other side is hit twice. This procedure is continued until the specimen breaks. Alternatively, the specimen may be fractured by loading in tension or by three-point loading on a universal testing machine. The method of breaking the specimen is not significant because the sole purpose of the nick-break test is to cause failure through the weld zone to determine the presence of discontinuities or defects.

Slag inclusions on steel may have a glass-like appearance or a dark contoured appearance. The nick-break fracture will travel from the cut metal to the slag inclusion and through the center of the inclusion. The location of a slag inclusion is sometimes smooth because the slag has been dislodged by the force of the hammer blows breaking the specimen. It is useful to match the two broken specimens together and rotate in good light to identify discontinuities. Sometimes discontinuities are easier to read on the fracture surface than the other matching side.

Porosity may be spherical or cylindrical in shape and may be isolated or grouped in clusters. The key to the identification of porosity is the shape and the absence of nonmetallic solid material. Porosity has a bright white or silvery appearance on steel if it is not exposed to the atmosphere. Surface-connected porosity usually has a black oxide appearance. The sound metal surface has a gray color without voids.

The observation of incomplete fusion depends on the joint design. If the joint is a single-V groove, base metal incomplete fusion would be planar in shape, showing the area on the groove face that is not fused. In some cases the grind marks on the original groove face can be identified.

It is helpful to place the two broken nick-break specimens together and identify the location of the first weld pass and the last, as well as the weld reinforcement area. If the discontinuity is located on the groove face or between weld passes and is planar in shape, it could be incomplete fusion.

Incomplete joint penetration is easy to identify in that it is always located at the weld root and is planar in shape. Incomplete joint penetration can be detected in the nick-break specimen before it is broken.

The broken nick-break specimen shows how deep the incomplete joint penetration extends into the weld metal. On steel, incomplete joint penetration is black to bluish in color.

In steel, cracks are flat and have a silvery color if they occur after welding is completed. If the fractured surface of a crack shows a blue oxide color, the metal cracked before the final weld passes were completed and the crack surface was heated to the temper color range by subsequent weld passes.

Fillet Weld Break Test. A *fillet weld break test* is a break test in which the specimen is tested with the weld root in tension. The fillet weld break test is used for the qualification of welders and is the only test required to qualify as a tack welder in accordance with AWS D1.1, *Structural Welding Code—Steel.*

Tack welding is a vital part of many fabrications such as fabrication of pressure vessels or structures. Except for fully automatic welding operations, most construction codes or standards have qualification rules for tack welders. A high-heat-input, mechanized process may be selected for the welding application, but the tack weld may be applied manually leading to very rapid

cooling and a brittle, crack-sensitive structure, commonly at the root of the weld. Subsequent weld passes with the high-heat-input process do not remove the cracks, but help them propagate further into the base metal and/or weld metal. Poorly applied tack welds are also the cause of entrapped slag, porosity, lack of penetration, and cracks.

If the WPS is qualified with preheating and postheating, the tack weld should be similarly qualified within the range specified. Most construction codes require tack welds of any length to follow a qualified WPS for the following reasons:

- tack weld is to be removed or left in place
- tack weld is attaching a component to the piece to be welded
- tack weld is incorporated into the weld as a tack in the root

To perform the fillet weld break test, a welder places a fillet weld on one side of a T-joint specimen. The specimen is placed in a press and bent to produce fracture at or near the weld. The fracture surface is examined for evidence of fusion with the root and absence of incomplete fusion or porosity larger than $3/32''$ in its greatest dimension. See Figure 31-23.

SPECIMEN PREPARATION

Fabrication codes and standards indicate how to obtain specimens from welds for mechanical testing. Good specimen preparation ensures that undesirable surface features are not introduced that have an undesirable effect on the test results.

Mechanical test specimen preparation is described in AWS B4.0, *Standard Methods for Mechanical Testing of Welds.* Specimen preparation may vary according to the type of weld. Safety practices must be followed when preparing specimens to prevent injury from grinding wheels, hot surfaces, or sharp edges.

Fillet Weld Break Test
Figure 31-23

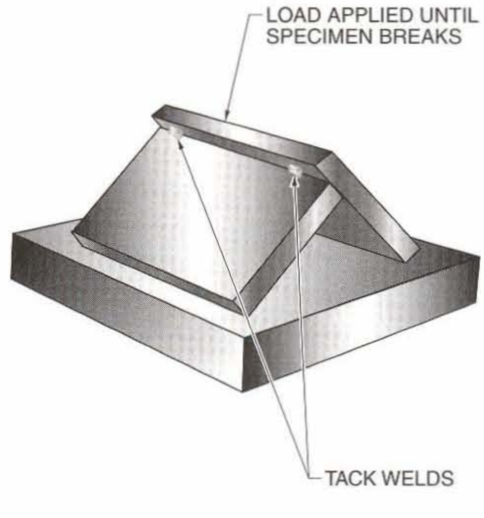


Figure 31-23. *The fillet weld break test is used by an inspector to qualify tack welds.*

Groove Welds

When using groove weld specimens, specific information must be recorded to document the results of the testing. When a double-groove weld specimen is used, identification stamps must be used to mark the side of the joint from which the test specimen was taken. Samples may be removed from specific locations in groove weld test plates and pipes to ensure representative specimens are obtained. See Figure 31-24. Groove weld specimens include tension specimens, root- and face-bend specimens, hardness specimens, fracture toughness specimens, and nick-break specimens.

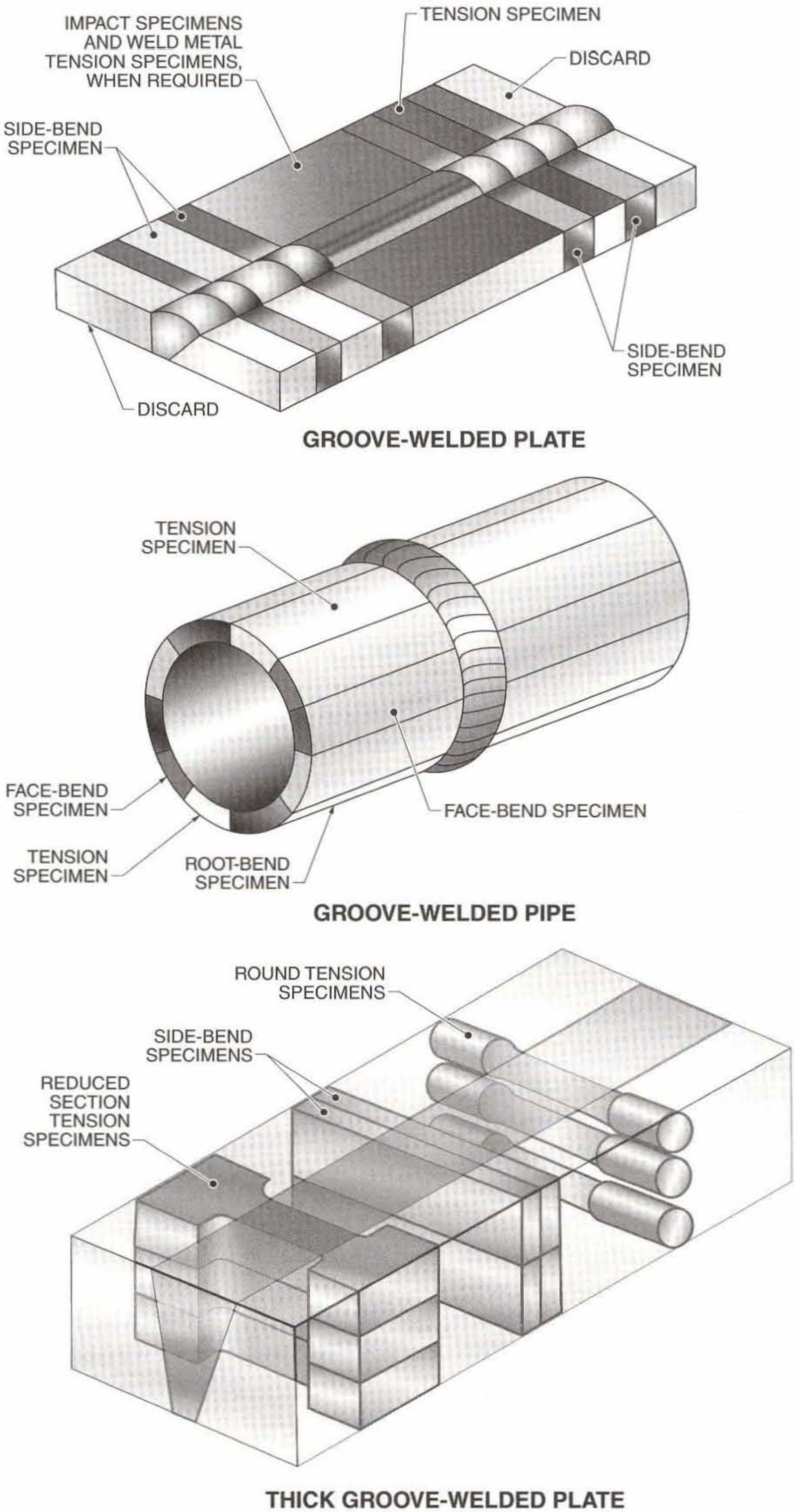
Specimen preparation must provide a smooth surface for testing. Nicks or sharp edges are undesirable because they introduce local stress raisers that might cause premature failure.

Tension Specimens. Tension specimens for groove welds may be rectangular or round. Deep machine cuts or surface tears must be avoided during surface preparation as they can cause invalid test results. Imperfections that are present in the gauge length that are incidental to welding do not need to be removed.

Rectangular specimens may be taken from plate or from tubing greater than $2''$ diameter and with wall thickness greater than $3/8''$. The weld orientation may be longitudinal or transverse. For tubing less than $2''$ diameter, only a full-section specimen may be tested.

Figure 31-24. *Specimens for destructive testing are balanced to obtain representative samples and results throughout groove-welded plate, groove-welded pipe, and thick groove-welded plate.*

Groove Weld Specimens
Figure 31-24



When the thickness of the test weld is greater than the capacity of the test equipment, the weld may be divided through its thickness into as many specimens as necessary to cover the full weld thickness and still maintain the specimen size within the equipment capacity. Usually, the results of partial-thickness specimens are averaged to determine the properties of the full-thickness joint. For specimens taken transversely to the centerline of the weld, only the ultimate tensile strength is determined because of possible material or structural inhomogeneities.

Round, all-weld metal specimens with the largest possible diameter that can be machined from a location are used. Specimens smaller than ¼″ diameter should not be used unless there is no other way to obtain the sample. Minor variations in the surface finish and test machine alignment may lead to irreproducible results due to the small size of the sample.

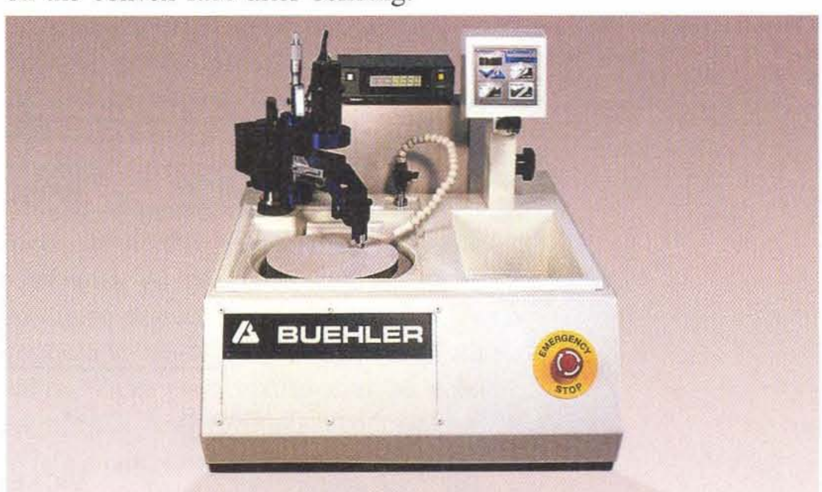
Bend Specimens. Bend specimens are used for welding procedure qualification and welder performance qualification tests. Similar preparation requirements are usually specific to groove weld and surfacing weld bend specimens. Bend specimens are prepared by cutting the weld metal and the base metal to form a rectangular cross-section specimen. At least ⅛″ of material must be mechanically removed from thermally cut surfaces to prevent the influence of heat on the test results. Longitudinal surfaces may be no rougher than 125 microinches (3 microns). Grinding or sanding marks should run parallel to the direction of bending to prevent them from acting as stress raisers that can lead to premature failure. Additionally, the corners of the specimen should be radiused to relieve excessive stresses.

Weld reinforcement and backing must be removed to be flush with the specimen surface. For welder performance qualification testing, undercuts may be removed, provided sufficient material remains to maintain the required specimen dimensions. When testing weld joints between base metals that have differing thicknesses, the specimen is reduced to a constant thickness using the thinner base metal.

The surfaces perpendicular to the weld axis are designated as the sides of the specimen. The other two surfaces are designated as the face or root surfaces. Transverse weld specimens may have the side, face, or root of the weld as the bend surface. Longitudinal weld specimens may have the face or the root of the weld as the bend surface.

The acceptability of a bend specimen is based on the size and/or number of defects that appear on the bend surface. The main purpose of the bend test for welding procedure qualification is to determine the ductility of a sound weld. Governing fabrication codes or specifications dictate exact acceptance or rejection criteria.

A discontinuity does not become a defect until it exceeds the limits allowed by the relevant code. A Project Engineer can ignore discontinuities that are less than the maximum, but all discontinuities must be recorded. AWS D1.1, *Structural Welding Code—Steel,* allows a total accumulation of discontinuities of ³⁄₃₂″. With the ASME Boiler and Pressure Vessel Code, bend specimens may have no open defects in the weld or the HAZ exceeding ⅛″ measured in any direction on the convex face after bending.



Buehler Ltd

A cross-sectioning system is used to prepare cross-sectioned specimens for welder performance qualification tests.

Etching may be required to determine whether the discontinuity is in the weld or the HAZ. Open discontinuities on the corners of specimens during testing are not considered unless there is evidence that they result from lack of fusion, slag inclusions, or other internal weld discontinuities.

Hardness Specimens. Hardness specimens for groove welds and surfacing welds are ground, machined, or polished depending on the type of hardness test to be performed. Surface preparation requirements become increasingly stringent as the size and depth of the indentation decreases. At the very minimum, it is necessary to remove rust and scale from the surface. Excessive heat must be avoided when preparing the test area of the specimen.

Weld metal hardness tests are only permitted either on weld joint cross section samples or on local areas of weld reinforcement that are ground smooth before testing. The edge of the indentation must be no closer than three times the major dimension of the indentation from the edge of the ground area of the reinforcement on welded assemblies. Specimens must be supported to prevent rocking under the tester. It may be necessary to grind the backside of the specimen to make it flat. The indenter should be perpendicular to the specimen. With a round specimen such as bar, it is usually necessary to grind a small area flat to make a test. The specimen must be thick enough so that an anvil effect (bulge) does not appear on the opposite side when the indentation is made. For the Rockwell and Brinell hardness tests, the specimen should be at least 10 times as thick as the depth of the impression. For the Vickers hardness test, the test specimen should be one and one-half times as thick.

For evaluation of weld metal hardness, the edge of the indentation must be within the weld metal and no closer than ⅛″ from the weld metal interface with the base metal. The minimum spacing between indentations depends on the type of test. If the indentations are too close together, there will be disturbed zones of metal. The minimum separation between indentations should be four diameters (4 d center to center) for the Brinell and Rockwell hardness tests and two and one-half diagonals (2 ½ D center to center) for the Vickers hardness test. See Figure 31-25.

Minimum Separation for Hardness Test
Figure 31-25

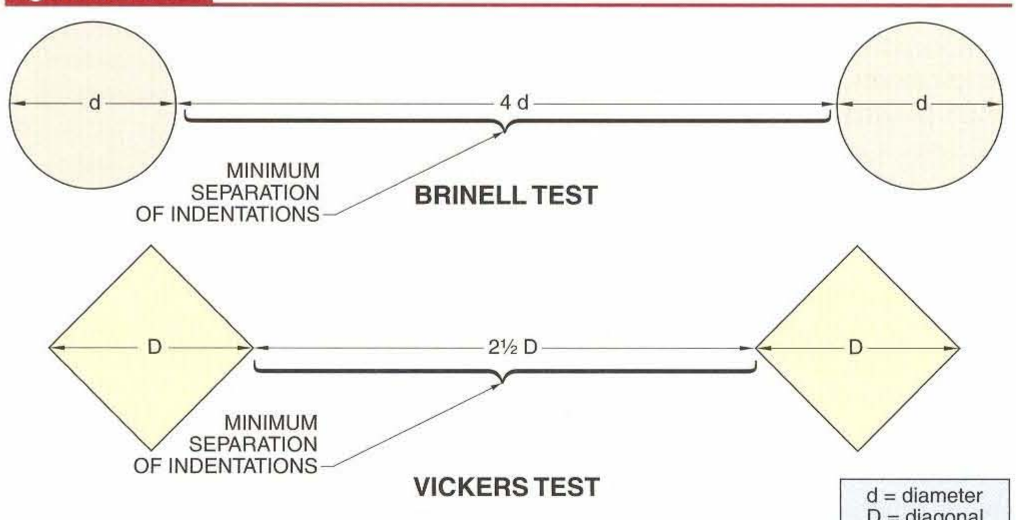


Figure 31-25. *A minimum separation of four diameters (4 d) for the Brinell hardness test and 2½ diagonals (2½ D) for the Vickers hardness test must be maintained to prevent disturbances between the base metal and weld metal zones.*

More than one reading must be taken to allow for surface irregularities and test specimen inhomogeneity. The minimum number of readings required for a specific test is determined by experience. For the Brinell test, three readings are usually taken and averaged. For the Rockwell and Vickers tests, three to five readings are usually taken and averaged.

Fracture Toughness Specimens. Fracture toughness tests may be performed to indicate the performance of the base metal, the HAZ, or the weld metal. A fracture toughness test uses a specimen that has a notch cut into it. The specimen is then tested to determine the fracture strength of the metal.

When the test is performed on the base metal or in the HAZ, the location of the notch is specified to be in the applicable region of the joint. When the test is performed on the weld metal, the width of the weld metal must be equal to or greater than the thickness of the specimen.

When specimens from double-groove welds are used, identification letters or numbers are stamped on the specimen to indicate the side of the joint from which the test specimen was taken. The location of identification stamps must not influence the failure of the specimen by creating a notch effect. Fracture toughness specimens for groove welds are made for Charpy V-notch tests, plane-strain fracture toughness tests, and drop weight tests.

The geometry and surface area of the notch are critical. Machining and finishing operations on the notch must adhere to applicable ASTM test standards. Nonstandard methods of notch preparation such as saw cutting may seem to be easier or cheaper, but they introduce variables into the test that could affect test results, and must never be used.

Nick-Break Specimens. Nick-break specimens for groove welds are prepared by machine cutting or flame cutting. The joint and base metal are cut to form a rectangular cross section. The weld is notched with a hacksaw, band saw, or thin abrasive wheel. Small weld assemblies may be tested using the complete assembly as the specimen. The notch is made at the weld edges to a depth of approximately ⅛″ and into the weld reinforcement to a depth of approximately 1⁄16″.

Fillet Welds

Fillet weld specimens include tension shear specimens, bend specimens, nick-break specimens, and hardness specimens.

Tension Shear Specimens. Tension shear specimens for fillet welds consist of longitudinal shear strength specimens and transverse shear strength specimens. Both types are sensitive to preparation procedures. The stress concentration at the root of transverse fillet welds increases with increasing root opening and variations in root opening may lead to inconsistent test results. Both transverse and longitudinal specimens are sensitive to HAZ cracking, undercut, and bead surface contour. The longitudinal edges of transverse test specimens should be machined to eliminate crack effects and to provide smooth surfaces. Corners should be lightly rounded.

A longitudinal shear strength specimen is made using two identical welded specimens that are machined and tack welded together to prevent bending during testing. The surface contour and size of the fillet welds must meet applicable fabrication codes or standards. A transverse tension shear specimen is made by cutting from plate containing lap-welded patches on both sides. Wider plate widths may be used to obtain multiple test specimens. When multiple specimens are prepared from a single welded assembly, the results for each individual specimen are reported.

Proper personal protective equipment including eye and ear protection and correctly tinted goggles must be worn to observe welding.

Residual stress measurement is a method of measuring the stress in materials produced by manufacturing processes such as welding.

Bend Specimens. Bend specimens for fillet welds are prepared for the longitudinal guided bend test or the wrap-around guided bend test. The bend specimen is prepared by making two fillet welds on a T-joint and machining the specimen to allow accommodation in the test jig. The specimen is positioned in the test jig and bent at ambient temperature. Deformation should occur in 30 sec to 2 min.

Nick-Break Specimens. Nick-break specimens for fillet welds can be prepared for pipe branch welds, pipe sleeve welds, and plate fillet welds. Pipe branch weld nick-break specimens are machine cut or flame cut samples taken from the crotch (point) area and at 90° from the crotch area. Nick-break specimens are approximately 2″ wide and 3″ long.

Pipe sleeve weld nick-break specimens can be either flame cut or machine cut. Specimens are equally spaced around the circumference of the pipe and must be at least 3″ wide and 6″ long.

Plate fillet weld specimens can be either flame cut or machine cut from the lap joint. Fillet weld specimens must be at least 3″ wide and 6″ long.

Hardness Specimens. Hardness specimens for fillet welds are prepared similarly to hardness specimens for groove welds. Specimens for fillet welds may be ground, machined, or polished, depending on the hardness test to be performed. Rust and scale must be removed from the surface. Excessive heat must be avoided when preparing the test area of the specimen. Specimens must be supported to prevent rocking during testing. If necessary, grind the backside of the specimen flat to prevent rocking.

Specimen Preparation Safety

Specimen preparation safety rules must be observed to prevent injury from sharp edges, hot metal, falling objects, or electrical items. In areas where grinding, burning, or welding are performed, there is a potential for toxic or flammable atmospheres that can be hazardous to the skin, eyes, and hearing. Such areas should not be entered without proper authorization.

Proper personal protective equipment must be worn, including eye and ear protection and correctly tinted glasses to observe welding in progress. Personnel should watch for tripping hazards and improper hose connections. Electrical cables and hoses that may be lying loose on a floor can be a tripping hazard. Hoses under pressure can break loose and inflict injury.

RESIDUAL STRESS MEASUREMENT

Residual stresses are locked-in stresses in materials that result from manufacturing processes such as casting, welding, forming, or heat treatment. Residual stresses can be detrimental, and when coupled with normal service stresses can be the predominant factor in fatigue and other mechanical failures. Residual stresses can also lead to stress corrosion cracking of some materials in specific corrosive environments. For example, welded carbon steel equipment and piping operating in hot caustic service must be given a stress relief heat treatment to prevent caustic stress cracking at welds, which are regions of high residual stress. The insidious aspect of residual stresses is that their presence generally goes unrecognized. Residual stresses may be measured. The most widely used technique to measure residual stresses is the hole-drilling method.

The Mathar-Soete drilling technique and the Gunnert drilling technique are the two types of hole-drilling methods used to measure residual stresses.

Hole-Drilling Method

The hole-drilling method is performed per ASTM E 837, *Method for Determining Residual Stresses by the Hole-Drilling Strain-Gauge Method.* A special three-element strain gauge rosette is placed on the specimen to be tested and, using a milling guide, a 1⁄16″ or 1⁄8″ diameter hole is drilled on the geometric center of the strain gauge rosette to a depth equal to the hole diameter. The relieved strains measured by the three radially oriented elements of the strain gauge provide information to calculate the maximum and minimum principal residual stresses and their orientation.

The hole-drilling method requires that a blind hole be drilled into a specimen or component. However, the hole-drilling method is considered semi-destructive if, as in many cases, it does not impair the structural integrity of the component, or if the hole can be welded up without introducing detrimental residual stresses. See Figure 31-26.

Tinius Olsen Testing Machine Co., Inc.

Figure 31-26. *The hole-drilling method is semi-destructive if it does not impair the structural integrity of the component.*

POINTS TO REMEMBER

1. The current edition of the controlling fabrication code or standard must be followed when making test welds and test specimens, and when conducting destructive tests.
2. Tensile specimens obtained from welded joints are typically rectangular, unless taken from a location where it is not possible to obtain a sample of rectangular cross section.
3. Bend testing is an economical way of judging weld quality to qualify a procedure or welder.
4. The guided bend test is the most commonly used ductility test for groove welds, surfacing welds, and fillet welds.
5. Hardness testing, although considered destructive, does not necessarily require that the specimen be cut into pieces, and is thus convenient and relatively rapid.
6. Toughness testing requirements depend on the specific applicable fabrication code or standard.
7. The Charpy V-notch test uses the energy produced by a dynamic load, and measures the energy needed to break a small machine-notched test specimen.
8. Break tests are also rapid methods of assessing weld quality and may be called out by specific industries.
9. Specimen preparation must provide a smooth surface for testing. Nicks or sharp edges are undesirable because they introduce local stress raisers that might cause premature failure.
10. Proper personal protective equipment, including eye and ear protection and correctly tinted goggles must be worn to observe welding.
11. Residual stress measurement is a method of measuring the stress in materials produced by manufacturing processes such as welding.

QUESTIONS FOR STUDY AND DISCUSSION

1. What artificial value is created for metals that do not exhibit a yield point?
2. Which has a lower value in a tensile test, yield point or ultimate tensile strength?
3. What are the two measures of ductility obtained in a tensile test?
4. What types of welds are usually assessed in a shear test?
5. A peel test can be applied to what type of weld?
6. Is a bend test a qualitative or quantitative assessment method?
7. What is a common test used for qualifying welding procedures and welders?
8. What types of weld orientations may be specified in a bend test?
9. What types of bend locations may be specified in a bend test?
10. Why is hardness testing commonly used to measure properties of materials?
11. What is the most common method of hardness testing?
12. What are the main types of indentation hardness tests?
13. What are static and dynamic conditions during toughness testing?
14. What is the most common toughness test for welded samples?
15. Is a material with a Charpy value of 60 ft-lb four times tougher than a material with a Charpy value of 15 ft-lb?
16. What is the name used to describe the transition of a material from ductile to brittle behavior and vice versa?

Nondestructive Examination 32

Weld Evaluation and Testing

Nondestructive examination is used to evaluate a part or weldment without destroying it or necessarily removing the part from service. Nondestructive examination discloses common surface and internal defects that occur with improper welding procedures or practices. A variety of testing devices are available that provide effective data about the reliability of a weldment. These devices are often more convenient to use than regular destructive testing techniques, particularly on large and costly welded units.

NONDESTRUCTIVE EXAMINATION (NDE) TERMINOLOGY

Nondestructive examination (NDE) is the development and application of technical methods to examine materials or components in ways that do not impair their future usefulness and serviceability. NDE techniques for welds are used to detect, locate, and measure discontinuities. Discontinuities in welds appear as flaws (indications). Appearance of the flaws varies depending on the NDE process. NDE results are compared with the allowable discontinuity limits in the applicable fabrication code or standard to determine acceptance or rejection of the weld.

A *flaw (indication)* is a discontinuity that can be detected through NDE techniques. Indications are categorized as relevant, nonrelevant, or false. A *relevant indication* is an NDE indication caused by a discontinuity that requires evaluation. A *nonrelevant indication* is an NDE indication caused by a discontinuity that, after evaluation, does not need to be rejected. A *false indication* is an NDE indication interpreted to be caused by a discontinuity at a location where no discontinuity actually exists. False indications are nonrelevant indications. See Figure 32-1.

A *defect* is one or more indications whose aggregate size, shape, orientation, or location fail to meet the acceptance criteria of the applicable fabrication code or standard. Defects are cause for rejection of the part or component.

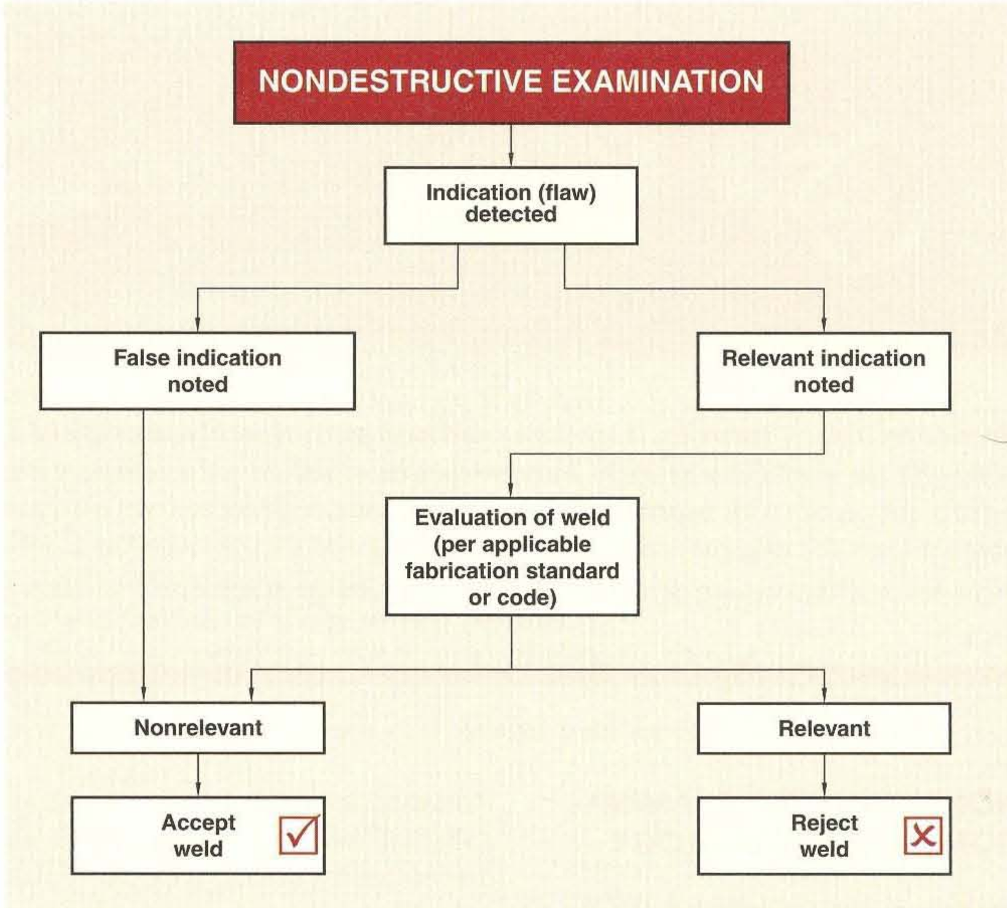
NDE is performed by an examiner, with the results evaluated by an inspector. Qualification and certification requirements for examiners and inspectors are described in the applicable fabrication code or standard. An *examiner* is a person who is qualified, or qualified and certified, to conduct certain types of NDE processes. Examiners are qualified and certified to American Society of Nondestructive Testing (ASNT) Recommended Standard SNT-TCIA. An *inspector* is a person who is qualified, or qualified and certified, to apply the results of NDE flaw characterization to determine whether the flaws meet the acceptance criteria of the applicable fabrication code or standard. See Appendix.

A flaw is not necessarily a defect. A flaw may be relevant (requiring evaluation by nondestructive testing), nonrelevant (rejection is not necessary after evaluation), or false (no discontinuity actually exists).

Nondestructive examination is performed by an examiner, who is a person qualified to conduct specific NDE processes.

An inspector is a person qualified to interpret nondestructive examination results according to the controlling code or standard for the job.

Figure 32-1. *Nondestructive examination is used to detect discontinuities in welds and determine if they are acceptable or must be rejected.*



Common nondestructive examination methods are visual, liquid penetrant, magnetic particle, ultrasonic, radiographic, and electromagnetic.

NONDESTRUCTIVE EXAMINATION TECHNIQUES

Specific NDE techniques are selected for the detection of different types of discontinuities. NDE techniques consist of visual examination (VT), liquid penetrant examination (PT), magnetic particle examination (MT), ultrasonic examination (UT), radiographic examination (RT), electromagnetic examination (ET), and proof testing.

VISUAL EXAMINATION (VT)

Visual examination is used to check surface condition; alignment of mating surfaces; conformance of the weld shape to a specific code or standard; and to locate leakage. Visual examination may be used before, during, or after welding.

Visual examination (VT) is application of the naked eye, assisted as necessary by low-power magnification and measuring devices, to monitor weld quality. A thorough examination of the weldment may disclose such surface defects as cracks, shrinkage cavities, undercuts, inadequate penetration, lack of fusion, overlaps, and crater deficiencies. VT measuring devices include rulers, calipers, straightedges, and welding gauges.

VT is generally used to determine surface condition, alignment of mating surfaces, conformance to specific shape, or to locate leakage. Direct VT requires sufficient access to place the eye within 24″ of the surface to be examined, and at an angle of not less than 30° to the surface to be examined. Mirrors are used to improve the angle of vision. Optical aids such as a magnifying glass can be used to assist in improving the quality of examinations. VT requires illumination with natural or supplemental white light at a minimum level of 50 fc (footcandles). The light source used, a verification report, and the VT technique used are documented in the examiner's report.

The limitation of visual examination is that there is no way to detect internal defects in the weld area. The weld may appear satisfactory, yet cracks, porosity, slag inclusions, or excessive grain growth may be present in the weld. VT is done before welding, during welding, and after welding.

Visual Examination Before Welding

Visual examination before welding consists of verifying the condition of materials to be welded, the conformity of partially assembled or tack welded parts, and the physical setup of the welding equipment.

Condition of Materials. The condition of the materials to be welded is verified by checking for scabs, seams, scale, and other harmful conditions on the base metal surface and for laminations in cut edges of plate. Conformance with specified dimensions is done by measurement and comparison with the specification drawing.

Conformity of Parts. Conformity of partially assembled or tack welded parts is verified after they are in position for welding. Joint dimensions, joint preparation, tack welds, and clamping must not impair the quality of the welded joint and must meet tolerances shown on the drawing. Joint dimensions include root spacing and offset. Joint preparation must ensure that rust, dirt, oil, paint, and other contaminants are removed from the weld area before welding.

Welding Equipment Setup. The physical setup of the welding equipment is verified by examining the condition of cables and connectors, how the cables are affixed to the welding machine, and how the ground cables are affixed to the work. Tack welds and clamps must maintain the root opening to ensure adequate penetration and alignment. Improper setup may lead to wasted power and erratic behavior during welding, caused by the following:

- Loose connections at the power source, work connector, or electrode holder
- Poor quality repair splices in the cable or a cable with broken strands
- Undersized cable for the required current or duty cycle
- Excessively long cables that cause an abnormal voltage drop

Visual Examination During Welding

Visual examination during welding provides details of the work while fabrication is in progress. VT during welding includes root pass examination, welding parameter verification, welding sequence monitoring, and weld bead quality checking.

Root Pass Examination. Root pass examination is done to ensure the quality of the root pass. The root pass is inspected for cracks, porosity, or blowholes, all of which should be ground out before continuation of welding.

VT is used to check that slag deposits have been removed by chipping, grinding, or gouging before welding on the opposite side of the groove. The root opening must be examined as root pass welding progresses because it may close up from the effects of thermal expansion and lead to lack of penetration. This is especially important for branch and angle joints that are more difficult to inspect after the weld has been completed.

Welding Parameter Verification. Altering the welding parameters can affect weld quality features such as penetration or dilution. Portable meters are used to ensure compliance with specified welding current and polarity.

Compliance with preheat and interpass temperature control parameters ensures that the metal temperatures are achieved by heat soaking and not by rapid surface heating.

All welders assigned to the welding job or joint should be identified and their qualifications checked for conformance to the job requirements. If the welder does not appear to have the necessary skill for the job, the inspector can, in consultation with the supervisor, request that the welder pass requalification tests.

Welding Sequence Monitoring. Welding sequence monitoring ensures that welding is first done on the most restrained joints or, whenever possible, allowing restrained joints a small amount

of movement and a measure of stress relaxation. The proper welding sequence helps prevent warpage and distortion.

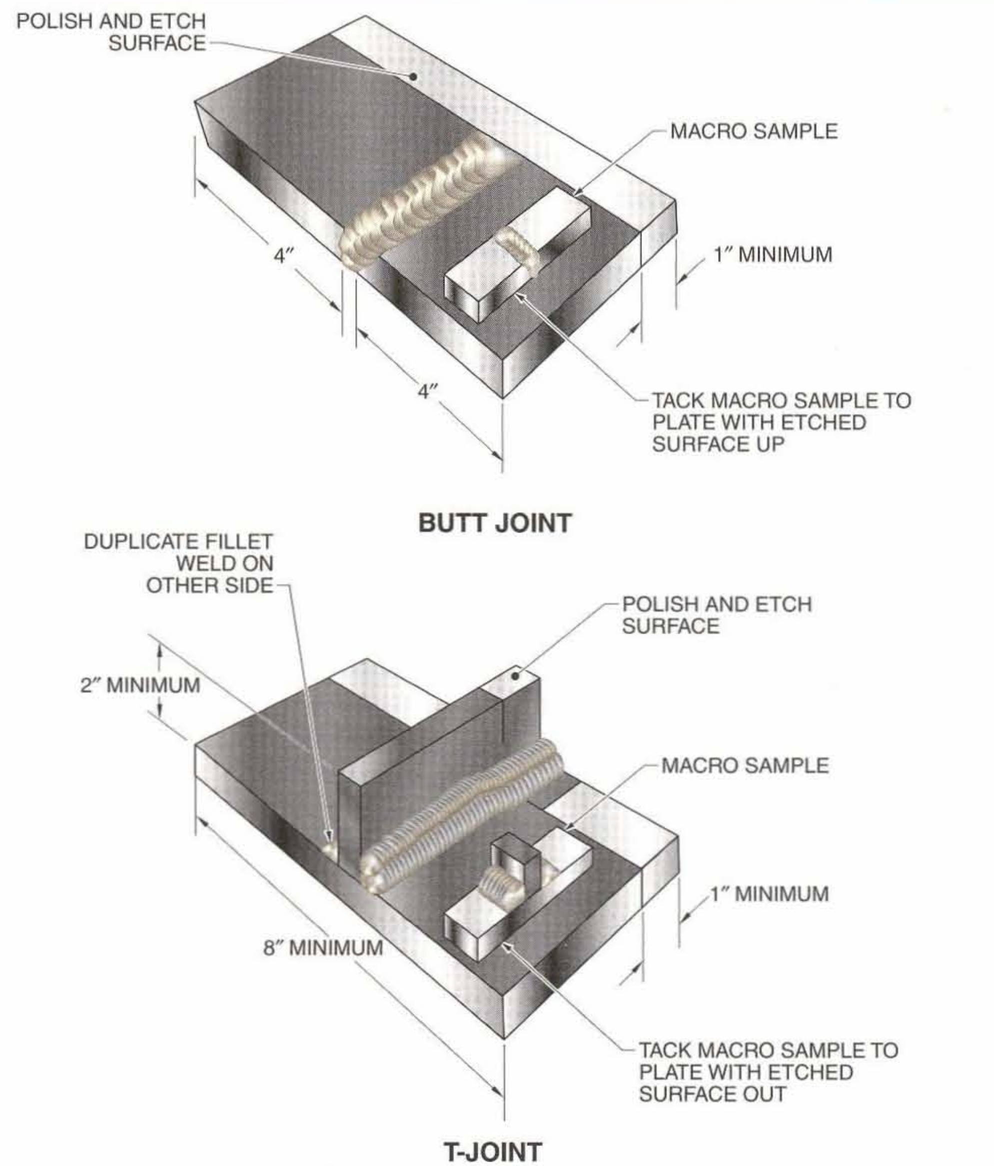
Weld Bead Quality Checking. Weld bead quality checking may be done using a workmanship standard. A *workmanship standard* is a section of a joint similar to the one in manufacture in which portions of each successive weld pass are shown. Each bead of the production weld may be compared with the corresponding bead of the workmanship standard. Multiple-pass weld beads are examined for evidence of ropy, piled-up beads, or bead rollover, which could trap slag. See Figure 32-2. Since workmanship standards usually represent ideal conditions, there must be allowances for production tolerances.

Visual Examination After Welding

Visual examination is performed after welding or repair welding to confirm the dimensional accuracy, weld appearance, and base metal integrity of the material. VT is also used to verify application of postwelding procedures. VT for repair welding ensures that a part meets the requirements of the original fabrication.

Figure 32-2. *A workmanship standard allows assessment of the quality of intermediate passes of multiple-pass welds.*

Workmanship Standards
Figure 32-2



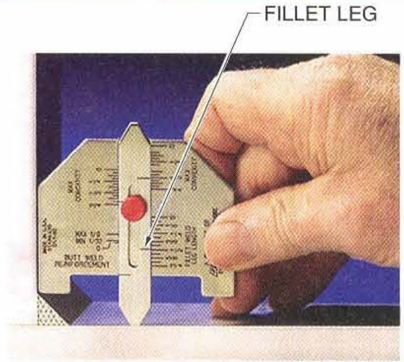
Dimensional Accuracy. Confirmation of dimensional accuracy ensures that distortion is within acceptable limits and that all welding has been done in accordance with the drawing. Weld reinforcement in groove and fillet welds is checked to ensure that it complies with the applicable fabrication code or standard. Weld dimensions are checked with a weld gauge. A *weld gauge* is a device for measuring the size and shape of welds. There are various kinds of weld gauges. See Figure 32-3.

Weld Appearance. Weld appearance is examined for evidence of transverse cracks, toe cracks, crater cracks, surface porosity, incomplete root penetration, undercut, underfill, overlap, joint misalignment, incomplete joint penetration, excessive or insufficient weld reinforcement, and excessive penetration.

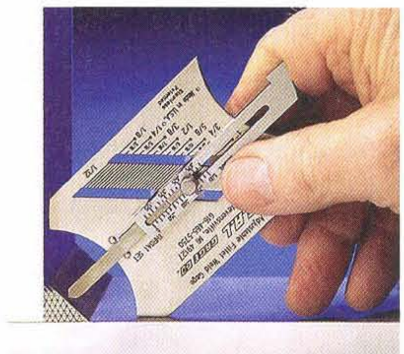
Some weld regions are more susceptible to discontinuities. Edges where fillet welds blend into base metal are susceptible to toe cracking and must be closely examined. Cracks are likely to be found in areas of starts and stops in the welding process and in welds with high restraint. Intermittent fillet welds are susceptible to crater cracks. Undercut that exceeds specification limits must be repaired by blend grinding, or in extreme situations, more filler metal must be added.

Base Metal Integrity. Base metal integrity must be maintained in areas where temporary attachments are welded on and subsequently removed, such as fit-up lugs, handling lugs, and machining blocks. After removal of these items, the attachment areas at the base metal must be ground smooth, and pits or tears must be filled with filler metal and ground. If indicated in the welding procedure, preheat, interpass temperature control, and postheating are required when thermal cutting or welding is done in attachment areas. Arc strikes and spatter must be removed in accordance with fabrication code or standard requirements.

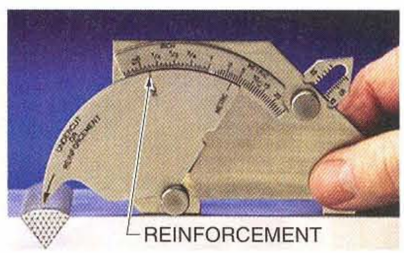
Weld Gauge Measurement
Figure 32-3



To determine size of a convex fillet weld, place gauge against toe of shortest leg of fillet and slide pointer out until it touches structure



To determine size of a concave fillet weld, place gauge against structure and slide pointer out until it touches the face of fillet weld



To determine reinforcement of a groove weld, place gauge so that reinforcement comes between legs of gauge and slide pointer out until it touches the face of groove weld

G.A.L. Gage Company

Figure 32-3. *A weld gauge allows the dimensions of a weld to be verified by the examiner.*

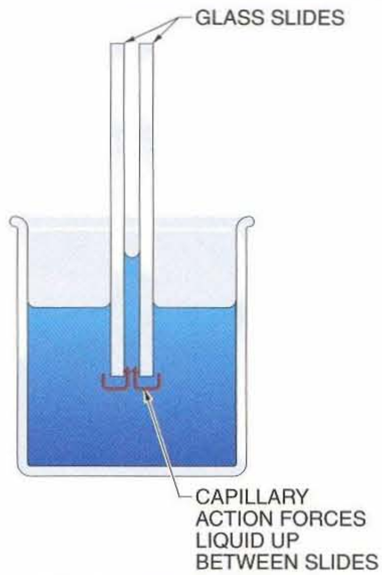
LIQUID PENETRANT EXAMINATION (PT)

Liquid penetrant examination (PT) is an NDE technique that uses dyes suspended in high-fluidity liquids to penetrate solid materials and indicate the presence of discontinuities. Application of a suitable developer brings out the dye and outlines the defect. Very small and tight discontinuities can usually be shown. When properly applied, PT is a reliable

method for detecting discontinuities open to the surface. However, it cannot be used on materials with excessively porous surfaces, such as sintered metals. Liquid penetrant examination uses the force of capillary action, which draws the liquids into all surface defects. See Figure 32-4.

Figure 32-4. *Capillary action occurs when a liquid, where it is in contact with a solid, is elevated or depressed.*

Capillary Action
Figure 32-4



> *Liquid penetrant examination is used to detect defects open to the surface, particularly in nonferrous metals such as aluminum, which cannot be examined by magnetic particle testing.*

Liquid Penetrant Examination Procedure

The PT procedure consists of several steps requiring a cleaner, penetrant, and developer. See Figure 32-5. A cleaner is used to ensure that the surface is clean and free from dirt, oil, grease, or other materials that may adversely affect the test.

A *penetrant* is a solution or suspension of dye. Penetrants for PT have low surface tension and a high cohesive force (high capillarity). If the discontinuity is small or narrow, such as a surface crack or surface porosity, capillary action assists the penetration. When the opening is gross, such as a hot crack, the liquid may be physically trapped as it flows over the surface rather than being retained by capillary action.

Figure 32-5. *A portable visible-penetrant, solvent-removable PT kit is useful in determining indications when the testing needs to be done at a remote location.*

A *developer* is a material that is applied to the test surface to accelerate bleedout and enhance the contrast of indications. Capillary action again assists the blotting action of the developer as it draws penetrant from the discontinuity. The penetrant appears on the surface as an indication corresponding to the location of the discontinuity.

To produce the best visibility of indications, liquid penetrant contains either a colored dye easily visible in white light, or a fluorescent dye visible under black (ultraviolet) light. Liquid penetrant dyes visible in white light are available in a variety of colors, although red is most common. Some liquid penetrants have dual sensitivity, meaning they are visible in white light or black light. To perform liquid penetrant examination (PT), follow the procedure:

1. Clean the surface to be examined.
2. Dry the surface to be examined.
3. Apply penetrant to the surface. Allow sufficient time for penetrant to seep into discontinuities.
4. Remove excess penetrant from surface.
5. Apply developer to draw penetrant back to the surface.
6. Visually examine the part to locate penetrant indications that have formed in the developer coating.

Once examination is completed, the part can be cleaned to remove the penetrant and developer residue. See Figure 32-6.

Liquid Penetrant Examination (PT) Procedure
Figure 32-6

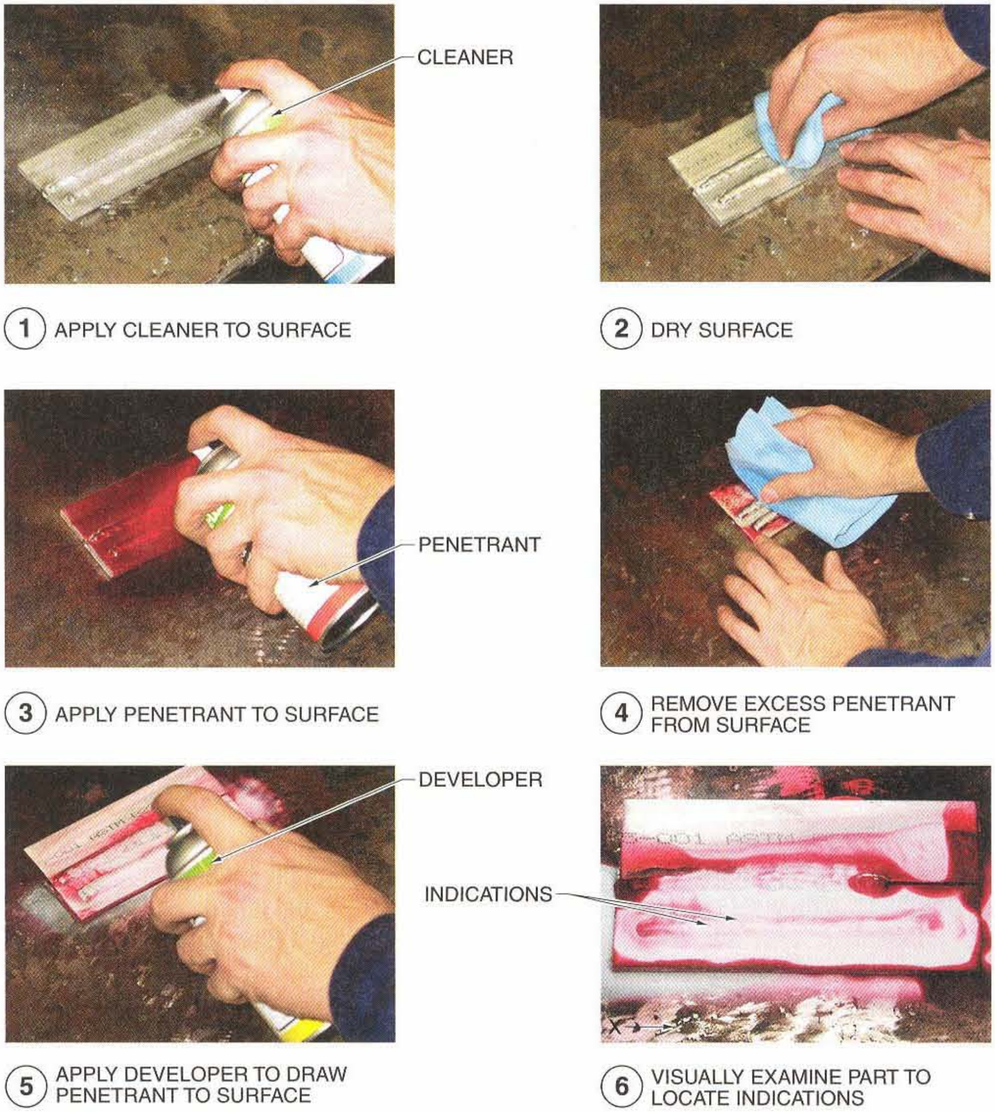


Figure 32-6. *Liquid penetrant examination consists of six steps, followed in a set sequence to ensure accuracy and reproducibility.*

The method of applying and developing fluorescent dyes is the same as for liquid dye penetrants; however, the fluorescent penetrant must be viewed under ultraviolet (black) light. Ultraviolet light causes the penetrants to fluoresce (glow) to a yellow-green color, which is a more clearly defined color than regular dye penetrants. Fluorescence is the emission of visible radiation by a substance as a result of, and only during, the absorption of black light radiation.

Surface Precleaning. The surface of a part must be completely clean and dry before administering liquid penetrant examination. Surface precleaning opens up surface discontinuities to penetration. Precleaning methods are detergent cleaning, vapor degreasing, steam cleaning, solvent cleaning, ultrasonic cleaning, rust and scale removal, paint removal, and etching. Precleaning methods that close up surface discontinuities must not be used.

Cleaning chemicals, such as sulfur and chlorine, must not have an adverse effect on the materials of construction. Nickel alloys may be damaged by degreasers containing sulfur; titanium alloys and stainless steels are affected

The surface of a part must be completely clean and dry before administering liquid penetrant examination.

by degreasers containing chlorine. Cracking may result if degreasers are not completely removed from test areas that are subsequently exposed to heat or high-temperature service.

Penetrant Application. Penetrant application is done by immersion, spraying, or swabbing (brushing) on dry parts over the areas to be examined. The surface of the weldment is coated with a thin film of the penetrant, which is allowed to remain on the surface for a predetermined amount of time, known as the dwell time. *Dwell time* is the total time penetrant is in contact with the component surface, including application and drain times. See Figure 32-7. Dwell time is directly related to the size and shape of anticipated discontinuities since discontinuity size determines the rate of penetration. For example, tight cracks require more than 30 min for

DWELL TIME					
Material	**Form**	**Type of Discontinuity**	**Water-Washable Penetration Time*†**	**Post-Emulsified Penetration Time*†**	**Solvent-Removed Penetration Time*†**
Aluminum	Castings	Porosity	5–15	5‡	3
		Cold Shuts	5–15	5‡	3
	Extrusions & Forgings	Laps	NR§	10	7
	Welds	Lack of Fusion	30	5	3
		Porosity	30	5	3
	All	Cracks	30	10	5
		Fatigue Cracks	NR§	30	5
Magnesium	Castings	Porosity	15	5‡	3
		Cold Shuts	15	5‡	3
	Extrusions & Forgings	Laps	NR§	10	7
	Welds	Lack of Fusion	30	10	5
		Porosity	30	10	5
	All	Cracks	30	10	5
		Fatigue Cracks	NR§	30	7
Steel	Castings	Porosity	30	10‡	5
		Cold Shuts	30	10‡	7
	Extrusions & Forgings	Laps	NR§	10	7
	Welds	Lack of Fusion	60	20	7
		Porosity	60	20	7
	All	Cracks	30	20	7
		Fatigue Cracks	NR§	30	10
Brass & Bronze	Castings	Porosity	10	5‡	3
		Cold Shuts	10	5‡	3
	Extrusions & Forgings	Laps	NR§	10	7
	Brazed Parts	Lack of Fusion	15	10	3
		Porosity	15	10	3
	All	Cracks	30	10	3
Plastic	All	Cracks	5–30	5	5
Glass	All	Cracks	5–30	5	5
Carbide-tipped Tools		Lack of Fusion	30	5	3
		Porosity	30	5	3
		Cracks	30	20	5
Titanium & High-temp Alloys	All		NR§	20–30	15
All Metals		Stress or Intergranular Corrosion	NR§	240	240

* for parts 60°F (16°C) to 125°F (25°C)
† in min.
‡ precision castings only
§ not recommended

Figure 32-7. *Penetrant dwell time is related to the size and shape of the discontinuities expected.*

penetration if an adequate indication is to be achieved. On the other hand, gross discontinuities may be suitably penetrated in 3 min to 5 min. After allowing time for the penetrant to flow into the defects, the part is wiped clean. Only the penetrant in the defects remains.

Ambient temperature and humidity can affect dwell time. Generally, the higher the ambient temperature, the shorter the dwell time. Excessively high temperature or excessively low humidity can cause penetrant to dry too rapidly. This makes the subsequent steps of PT difficult, if not impossible. For reliable PT, the penetrant must remain wet. In some cases rewetting of the test surface is required. If penetrant has been allowed to dry, the test must be started again, beginning with surface preparation. Heating the part is not recommended. Although heating of the part accelerates penetration and shortens dwell time, it also causes evaporation of penetrant and reduces sensitivity.

Dwell time is determined by the type of anticipated discontinuities and the recommendation of the penetrant manufacturer.

Penetrant Removal. Penetrant removal must ensure that all penetrant is removed from the surface without disturbing any penetrant that has entered a discontinuity. Penetrant removal is done after dwell time is complete, or after dwell time plus emulsification time. Complete penetrant removal is required to prevent the formation of false indications.

Penetrants used in water-rinsable PT have a built-in emulsifier to permit removal of the penetrant with a water rinse. Water-rinsable penetrants are sometimes called self-emulsifiable penetrants.

Post-emulsified penetrants are removed with a water rinse after completion of dwell time plus emulsification time. Light scrubbing may be required for complete penetrant removal.

Solvent-removable penetrants require a solvent designated by the penetrant manufacturer for effective penetrant removal. Solvents should not be substituted without consulting the manufacturer. Excess penetrant is first wiped from the test surface with clean, lint-free, solvent-dampened towels. Solvent is never applied directly to the surface because it might wash out or dilute the penetrant in a discontinuity.

Developer Application. After the penetrant has been sufficiently wiped clean, an absorbent material called a developer is applied to the weldment and allowed to remain until the liquid from the imperfection flows into the developer. Developer application consists of coating the test surface with a material to accelerate bleedout and enhance indication contrast. Developer acts as a blotting agent, accentuating the presence of penetrant in a discontinuity. Developer also serves as a color-contrast background for the dye. Developer causes the penetrant within a discontinuity to seep over a greater area so that the size of the indication in the developer is larger than the actual size of the discontinuity. See Figure 32-8. Once the developer is applied, the dye clearly outlines any defects. Developer is selected according to the manufacturer's recommendation for the type of penetrant used.

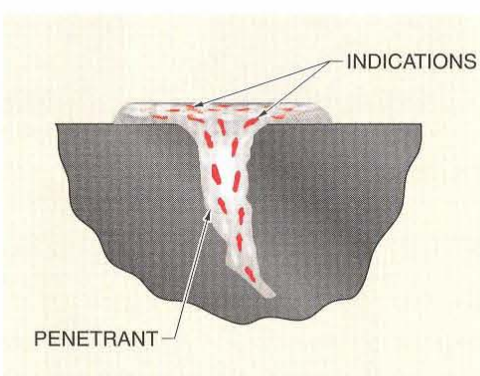
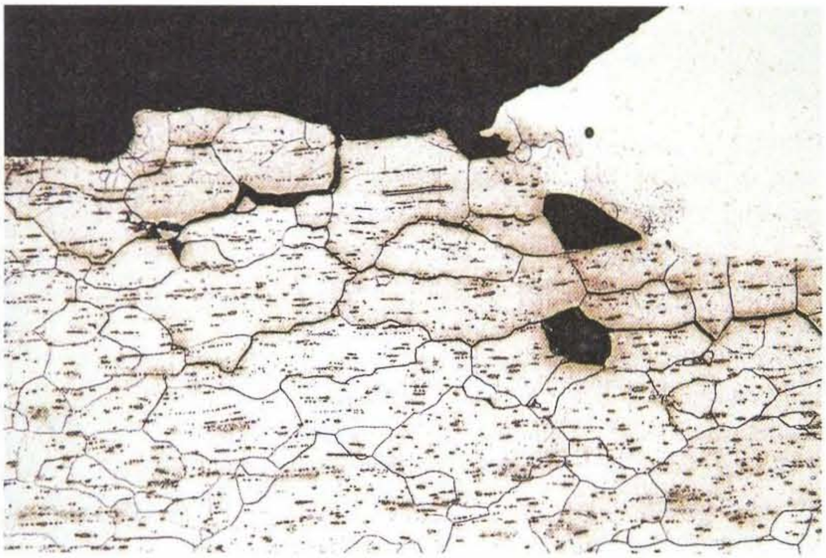


Figure 32-8. *Developer causes the penetrant to bleed within the discontinuity, causing it to seep over a greater area, making the indication appear larger than the actual discontinuity.*

PT Examination. Examination of the test surface occurs after sufficient developing time has been allowed. *Developing time* is the elapsed time between the application of the developer and the examination of the part. Insufficient developing time does not allow indications to fully develop. Excessive developing time causes indications to blur or distort. Correct developing time depends on the developer used. Generally, developing time is about half of dwell time.



Stork Technimet, Inc.

Magnetic particle examination may be used on a magnetic stainless steel to locate hot cracks near the surface of the weld.

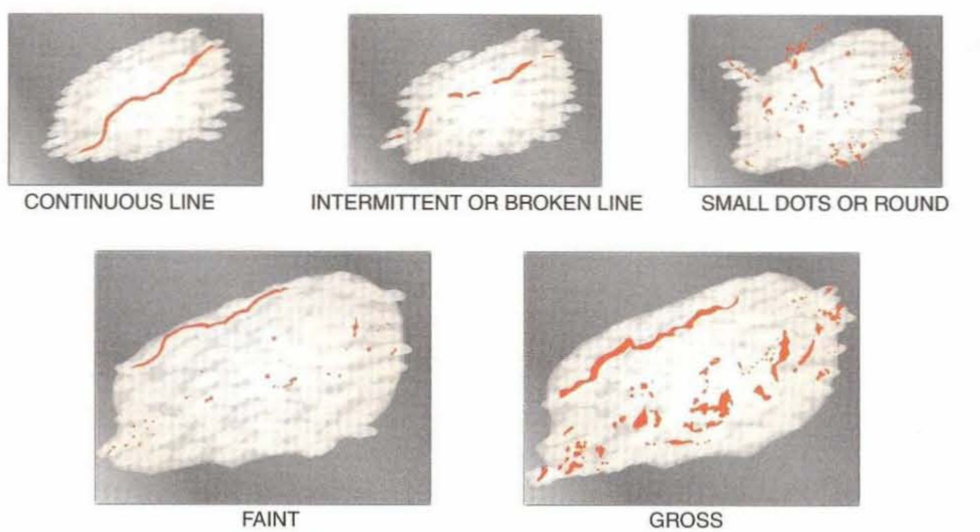
False or nonrelevant PT indications occur when the surface contour of the weld contains sharp depressions between weld beads that interfere with complete cleaning and complete penetrant removal. Such surfaces should be ground smooth before examination. Since smooth grinding may not be cost-effective, other NDE methods may be preferred. Diffused or weak indications appearing over a larger area are usually false indications and indicative of improper cleaning.

Nonrelevant indications are caused by surface discontinuities from the fabrication process or part geometry, which have no bearing on the service life of a component. Nonrelevant indications may appear on press fit, keyed, splined, or riveted objects, or on castings containing an adherent scale or burned-on sand.

Relevant indications are caused by discontinuities. Relevant indications are categorized as continuous line, intermittent or broken line, small dots, or round. Indications may also be categorized as faint or gross, depending on their dimensions. See Figure 32-9. Relevant indications must be evaluated against the requirements of the applicable fabrication code or standard.

Figure 32-9. *Relevant indications fall into several categories: continuous line, intermittent or broken line, small dots, or round.*

Liquid Penetrant Examination (PT)—Relevant Indications
Figure 32-9



All possibilities that the indication is nonrelevant or false are first eliminated, after which the cause of the indication may be determined. It is then determined whether the indication is allowable per the applicable fabrication code or standard.

Recording Liquid Penetrant Examination Results

PT results are recorded by the examiner in a format that records the PT method, base metal, filler metals, weld procedure identification, and location and interpretation of discontinuities.

MAGNETIC PARTICLE EXAMINATION (MT)

Magnetic particle examination (MT) is an NDE method that uses a strong magnetizing current and a finely divided powder to detect defects. Magnetic particle examination uses magnetic leakage fields and suitable indicating materials to detect surface and near-surface discontinuity indications in ferromagnetic metals.

MT consists of magnetizing the area to be examined and applying magnetic particles to the surface. However, not all materials can be magnetized.

Magnetic particles concentrate at the defect. Impurities or discontinuities in the magnetized material interrupt the lines of magnetic force, showing the size, shape, and location of defects. See Figure 32-10. The patterns are usually characteristic of the type of discontinuity detected.

MT detects surface discontinuities and defects resulting from very fine cracks, lack of fusion, and inclusions or internal flaws that are slightly below the surface of the weldment, including those too fine to be seen with the naked eye. All types of surface cracks can be detected using magnetic particle examination since it is one of the most reliable techniques for nondestructive examination.

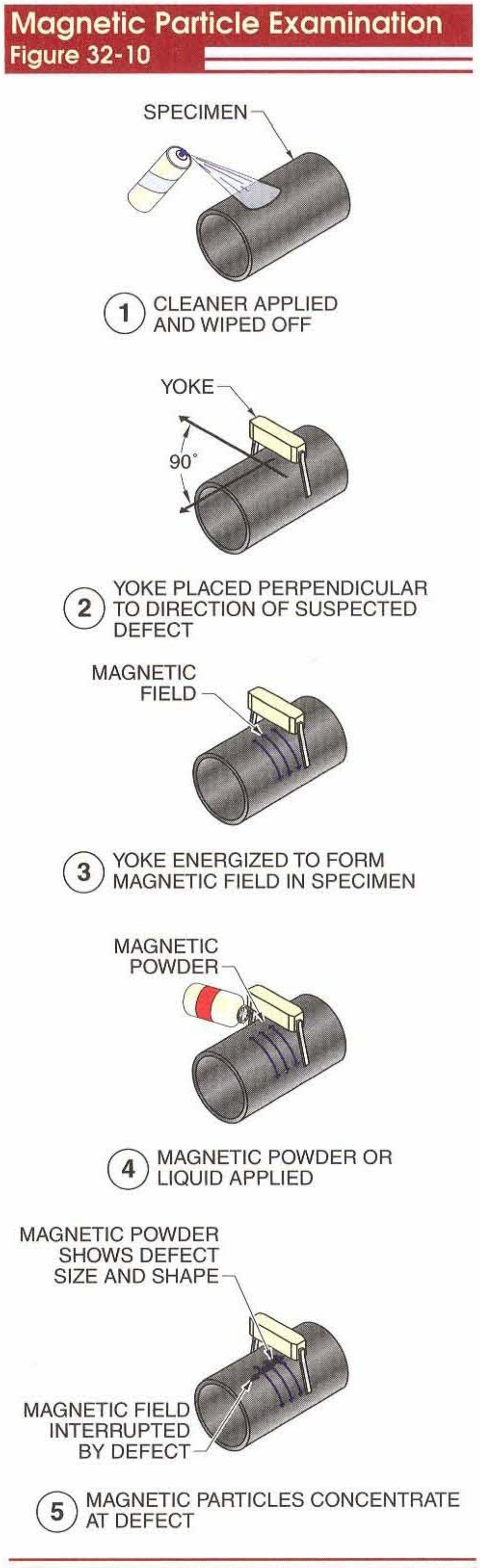


Figure 32-10. *Magnetic particle examination consists of magnetizing the area to be examined and applying magnetic particles to the surface.*

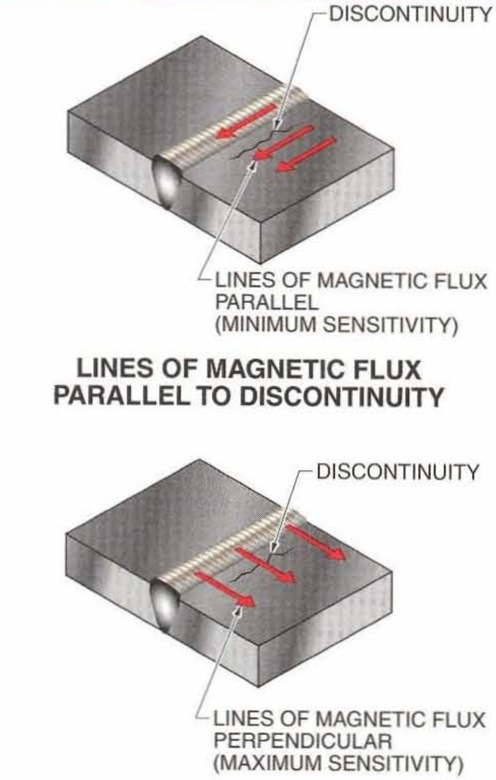
Magnetic sensitivity is greatest for surface discontinuities, but diminishes rapidly for subsurface discontinuities with increasing depth. Typical discontinuities detected by MT include cracks, overlap, and laminations.

Magnetic particle examination is used to detect surface or near-surface discontinuity indications in ferromagnetic metals.

Maximum sensitivity with MT is obtained from linear discontinuities oriented perpendicular to the lines of magnetic flux. For this reason, each area should be examined twice, with the lines of magnetic flux during the second examination approximately perpendicular to the lines of flux during the first examination. See Figure 32-11.

Figure 32-11. *Maximum sensitivity is obtained when the lines of magnetic flux are perpendicular to the orientation of the discontinuity.*

Lines of Magnetic Flux
Figure 32-11



A magnetic field may be induced in the part by circular magnetization or longitudinal magnetization.

Magnetic Particle Examination Principles

A magnetic field can be generated by the flow of electricity (magnetizing current) through a conductor. The generated magnetic field reveals the presence of discontinuities when magnetic particles are applied to the surface.

The *magnetic field* is the space within and around a magnetized part or conductor carrying current in which a magnetic force is exerted. Ferromagnetic materials are influenced by magnetic fields. A *ferromagnetic material* is a material that can be magnetized or strongly attracted by a magnetic field. Ferromagnetic materials include carbon and low-alloy steels; martensitic and ferritic stainless steels; and tool steels.

When a magnetic field is established in a piece of ferromagnetic material containing one or more discontinuities, minute magnetic poles are set up at the discontinuities. Discontinuity sites have a stronger attraction for magnetic particles than the surrounding area of material. A *magnetic particle* is a finely divided ferromagnetic material that is capable of being individually magnetized and attracted to distortion in a magnetic field.

When a part with discontinuities is magnetized, a magnetic leakage field is produced at the discontinuities. The *magnetic leakage field* is the magnetic field that leaves or enters the surface of a part at a discontinuity or change in section configuration of a magnetic circuit. See Figure 32-12. Magnetic particles congregate at leakage fields and indicate the approximate shape of a discontinuity. Magnetizing current used for MT is circular or longitudinal.

Magnetic Leakage Field
Figure 32-12

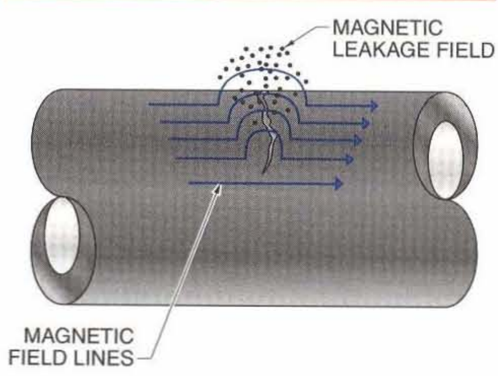


Figure 32-12. *A disruption in the magnetic field causes a magnetic leakage field as the magnetic field lines enter or leave a discontinuity, resulting in an accumulation of magnetic particles at the location of the discontinuity.*

Circular Magnetization. *Circular magnetization* is a concentric magnetic field produced by a straight conductor, such as a piece of wire, carrying an electrical current. Circular magnetization is produced by a contact head, central conductor, or prods. See Figure 32-13.

A *prod* is a set of hand-held electrodes used to transmit the magnetizing current from the source to the material being inspected. Prods are used where the size or location of the part does not permit the use of contact heads. The magnetic field is distorted by the interaction of the fields produced by the prods.

Circular Magnetization
Figure 32-13

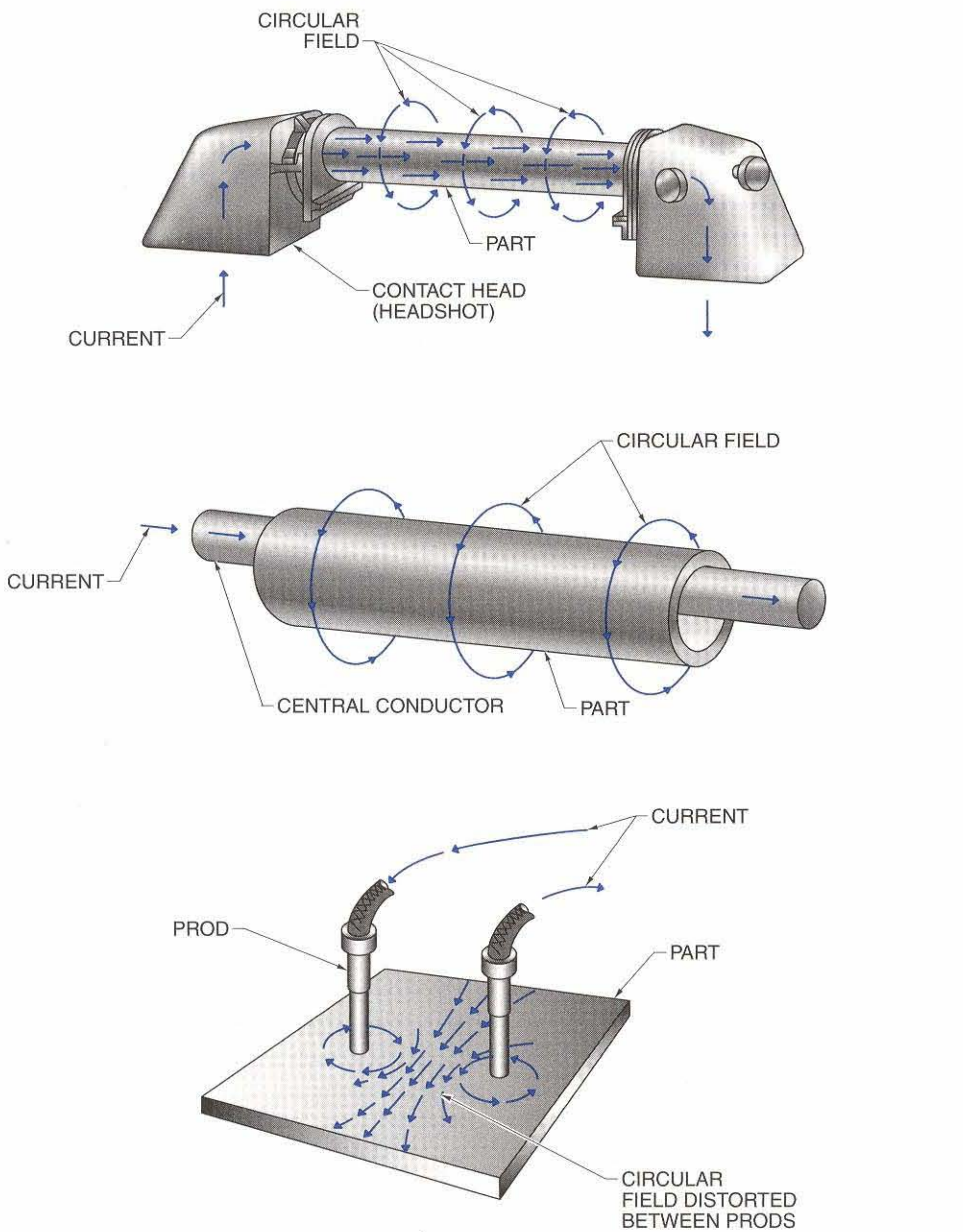


Figure 32-13. *Circular magnetization is produced by contact heads, prods, and central conductors.*

Longitudinal Magnetization. *Longitudinal magnetization* is a magnetic field produced when the current-carrying conductor is coiled and the magnetic field is parallel to the axis of the coil. The magnetic field strength produced within a coil increases in proportion to the number of loops within the coil. Longitudinal magnetization is achieved by coil or yoke. See Figure 32-14.

A coil is used when the length of the part is several times larger than its diameter. The coil is constructed by wrapping the electrical wire around the part. A *yoke* is a temporary horseshoe magnet made of soft, low-retentivity iron that is magnetized by a small wire wound around the horizontal bar. When current is passed through the wire, the magnetic flux lines flowing between the heads of the yoke in contact with the part induces a magnetic field in the part. No current flows through the part with the coil or yoke methods.

With both circular magnetization and longitudinal magnetization, the magnetic field orientation must be perpendicular or nearly perpendicular to the discontinuities to produce indications. The best results are obtained when the magnetic field is at right angles to the discontinuity and the current flow is parallel to the discontinuity.

Magnetic Particle Examination Procedure

MT procedure requirements are steps that must be followed to create an effective MT examination. MT procedure requirements include surface preparation, MT method identification, and demagnetization.

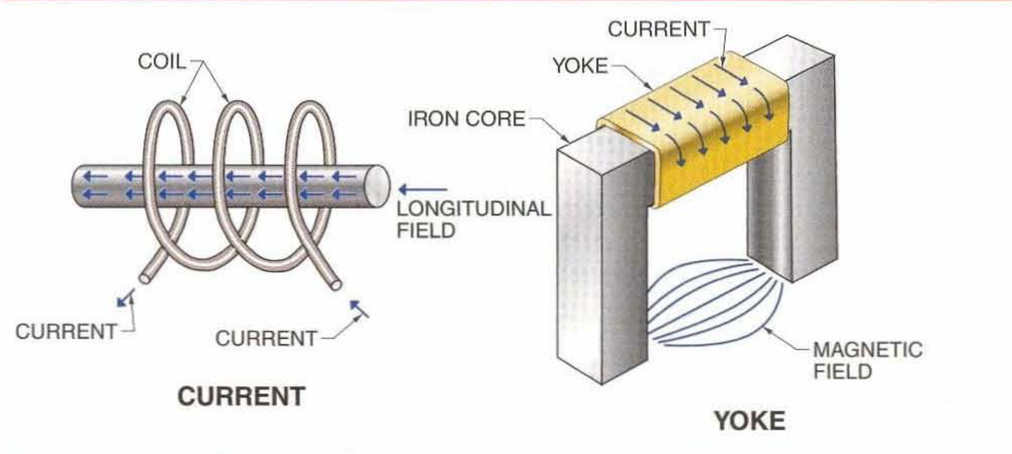
Surface Preparation. Surface preparation must ensure that the test surface is dry and free of dirt, paint, grease, lint, scale, weld flux, weld spatter, oil, and/or other extraneous matter that might interfere with the formation or interpretation of magnetic particle indications. For welds, the area to be prepared must include the weld and at least 1½″ of base metal on both sides of the weld, measured from the toe of the weld.

MT Method Identification. MT method identification determines which process to use for MT examination. The method of magnetization (continuous or residual) and the state of the magnetic particles (wet or dry) to be used determine the method.

The *continuous magnetization method* is an MT examination technique in which the magnetic particles are applied while the magnetizing force is maintained. The current continues to flow the entire time the magnetic particles are

Figure 32-14. *Longitudinal magnetization is achieved using a coil or yoke.*

Longitudinal Magnetization
Figure 32-14



applied and excess magnetic particles removed. If the current is turned off before excess particles are removed, the only indications remaining will be those held by the residual magnetic field.

The *residual magnetization method* is an MT examination technique in which magnetic particles are applied after the magnetizing force has been disconnected. The residual method relies on the amount of residual magnetism retained in the test specimen. The accuracy and sensitivity of the residual method depends on the strength of the residual magnetic field. The residual method cannot be used on materials with low retentivity, such as low-alloy steel. *Retentivity* is the ability of a material to retain a portion of the applied magnetic field after the magnetizing force has been removed.

The *dry magnetization method* is an MT examination technique in which the magnetic particles are in a dry powder form. The *wet magnetization method* is an MT examination technique in which the magnetic particles are suspended in a liquid medium. Particles for the wet magnetic method are available in red or black. Red improves visibility on dark surfaces. Sensitivity of the wet method may be increased by coating the magnetic particles with a dye that fluoresces brilliantly under ultraviolet (black) light.

Demagnetization. *Demagnetization* is the elimination or reduction of residual magnetism created by MT. Demagnetization is only necessary if the residual field interferes with subsequent machining operations or arc welding, or on structures where sensitive instruments may be affected.

Demagnetization is mandatory for engine and machine parts that have been strongly magnetized. Filings, grindings, and chips resulting from operational wear are attracted to magnetized parts and interfere with performance. Demagnetization is also mandatory in aircraft construction for all steel parts in close proximity to the compass.

Selecting Magnetic Particle Examination Methods

Portable MT units are used for most weld testing. The MT method is determined by the size and shape of the workpiece and the expected discontinuities. MT methods commonly used for weld testing are dry continuous using the prod method and dry continuous using the yoke method.

Prod Method. The *prod method* is a wet or dry continuous method in which portable prod-type electrical contacts are pressed against the areas to be examined to magnetize them. Arcing may cause burns and cracking of the base metal. To prevent arcing, a remote control switch may be built into the prod handles, allowing the current to be turned on only after the prods have been properly positioned.

Wet or dry magnetic powder is applied to the surface while the magnetizing current is switched on and the prods are in contact with the surface. For efficient coverage of welds, the prods must be crisscrossed. See Figure 32-15.

Magnetic powder may be applied by the dry magnetization method or the wet magnetization method.

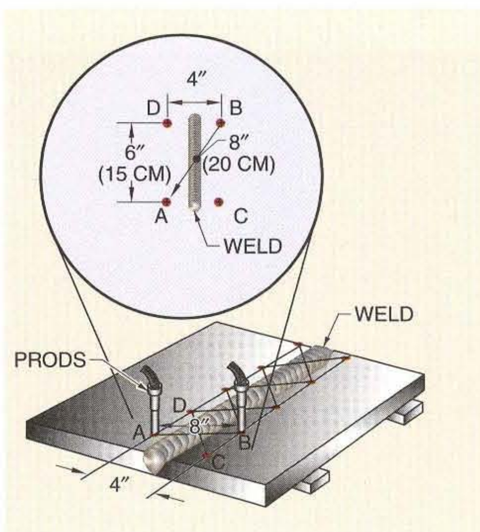


Figure 32-15. *For efficient coverage of welds when using the prod method, prods must be crisscrossed and spaced appropriately.*

Yoke Method. The *yoke method* is a dry continuous method of MT for detection of surface discontinuities. When the energized yoke is placed on the part, the flux flowing from the

Demagnetization is mandatory for parts in critical service, such as engines and aircraft, that have been strongly magnetized. Filings, grindings, and chips resulting from operational wear are attracted to magnetized parts and interfere with performance.

yoke's north pole, through the part, to the south pole induces a local longitudinal field in the part. If magnetic powder is applied sparingly to the area between the poles, surface discontinuity indications are easily seen. However, the magnetic field produced by the yoke does not lie entirely within the part. An external field is present that is a deterrent to locating subsurface discontinuities.

After the test surface is prepared, the yoke is positioned on the surface and the current is turned on. Magnetic powder is lightly dusted on the surface being examined and the excess removed with a gentle air stream. The particle pattern is observed for indications. After examination is complete, the current is turned off. The examination procedure is repeated with the yoke turned at approximately a right angle to its former position. The yoke is then repositioned over the next area with sufficient overlap to ensure 100% coverage of the area to be examined. After examination and recording of discontinuities, the test surface is completely wiped clean with a cloth.

Baker Testing Services, Inc.

A cracked truck suspension is tested by magnetic particle examination. The magnetic yoke is attached to the failed part and the yellow magnetic powder is drawn to, and identifies, the crack.

Magnetic particle test indications are commonly preserved with the MT results. The most common method of preserving indications is the transparent tape transfer technique. Other methods that may be used are the lacquer transfer technique and the nonfluorescent or fluorescent photographic techniques.

Magnetic Particle Examination Indications

Magnetic particle examination indications are examined after the magnetic particles have been allowed to interact with any discontinuities. For MT examination follow the procedure:

1. Identify indications.
2. Reject false indications.
3. Interpret relevant indications according to applicable fabrication code or standard to determine if they are cause for rejection or repair.
4. Record relevant indications.

Crack types detected by MT are crater cracks, transverse cracks, and toe cracks. MT indications for crack-type discontinuities are sharply defined, tightly held, and usually heavily built up with powder. The deeper the crack, the heavier the magnetic powder buildup. Crater cracks can be a single line in any direction or star-shaped. MT indications for subsurface cracks are fuzzier and their sharpness decreases with an increase in crack depth below the surface.

The magnetic powder patterns of subsurface porosity detected by MT are fuzzy and not pronounced, yet are readily distinguished from indications of surface porosity. MT detects slag inclusions as a pattern similar to subsurface porosity when high magnetizing field strength is used.

Incomplete fusion appears as an accumulation of powder at the edge of a weld. The pattern is sharper the nearer the discontinuity is to the surface. Incomplete fusion is rarely visible at the surface and so the magnetic powder indication will not be clear and sharp.

Incomplete penetration may exhibit a magnetic powder pattern similar to a subsurface crack. It will be wide and fuzzy, but the pattern should be linear.

MT may produce false indications that have no significance for weld quality. False indications are mostly attributed to physical contour effects or magnetic characteristic changes. Physical contour effects include a change in section thickness or a hole in a part. The magnetic particle patterns for physical contour effects are usually easy to identify by their location and the shape of the part at the location.

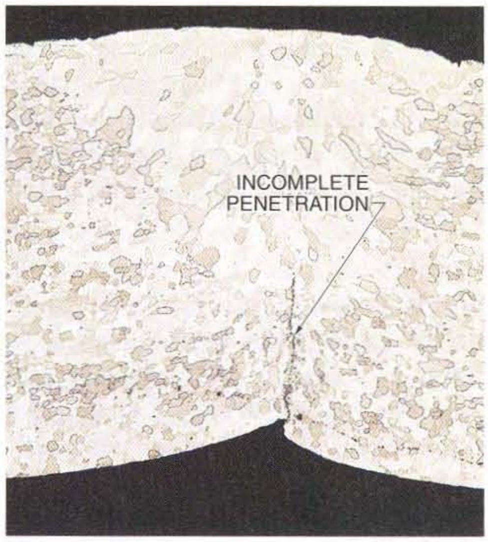
MT is not recommended for dissimilar metal welds. When two materials with differing magnetic properties are joined, such as carbon steel welded with austenitic stainless steel filler metal, an indication develops at the junction. The indication is difficult to distinguish from a crack.

Recording Magnetic Particle Examination Results

The record form for MT indications shall contain a sketch showing the geometry of the part, cable arrangement and connections, and areas of examination where adequate field strength was obtained. The information should be accompanied by the results of the examination such as a sketch or permanent record.

ULTRASONIC EXAMINATION (UT)

Ultrasonic examination (UT) is an NDE method that introduces ultrasonic waves (vibrations) into, through, or onto the surface of a part and determines various attributes of the material from its effects on the ultrasonic waves. Ultrasonic examination is very sensitive, and is capable of locating very fine surface and subsurface cracks, as well as other internal defects. High-frequency vibrations or waves are used to locate and measure defects in both ferrous and nonferrous materials. A high-frequency sound beam is directed into a part on a predictable path. The sound beam is reflected back when it encounters an interruption in the continuity of a material. The reflected beam is detected and analyzed to define the presence and location of the discontinuity. See Figure 32-16.



Stork Technimet, Inc.

Figure 32-16. *Ultrasonic examination can be used to find subsurface discontinuities such as incomplete penetration.*

If a high-frequency vibration is sent through a sound piece of metal, a signal will travel through the metal to the other side, be reflected back, and be shown on a calibrated screen of an oscilloscope. Any discontinuities within a structure interrupt the signal and reflect it back sooner than the signal of the sound piece of material.

The reflection is shown on the oscilloscope screen and indicates the depth of the defect. Only one side of the weldment needs to be tested.

The primary purpose of UT for welds is to detect laminar discontinuities such as cracks or lack of fusion that might be more difficult to detect with other NDE techniques. A *laminar discontinuity* is a discontinuity that is relatively thin and flat. UT can also be used to detect laminations, shrinkage voids, porosity, slag inclusions, incomplete joint penetration, and other discontinuities in welds. With the proper technique, the position and depth of the discontinuity can be determined, and in some cases, the size of the discontinuity. All types of joints can be evaluated by UT and the size and location of defects can be measured.

Ultrasonic Examination Principles

The principles of ultrasonic examination are based on the ability of ultrasonic waves (vibrations) to pass through metal and to be reflected at a discontinuity. A search unit is used to send and receive the ultrasonic waves. A couplant is required to improve transmission of ultrasonic energy. Electronic components are required to generate the ultrasonic waves and record testing information.

Search Unit. A *search unit (probe)* is an electroacoustic device for transmitting or receiving ultrasonic energy, or both. A *crystal (transducer)* is the piezoelectric element in a search unit that converts electrical energy to ultrasonic energy and vice versa.

When excited with high-frequency electrical energy, the crystal produces mechanical vibrations. The crystal also receives reflected vibrations, transforming them into low-energy electrical impulses.

Search unit configurations in weld testing are straight beam and angle beam. A *straight beam* is a vibrating pulse wave traveling perpendicular to the surface. An *angle beam* is a vibrating pulse wave traveling other than perpendicular to the surface.

Couplant. A *couplant* is a liquid substance used between the search unit and the test surface to permit or improve the transmission of ultrasonic energy. A gas interface such as air reflects almost all of the ultrasonic energy it receives. The purpose of the couplant is to exclude air between the transducer and the test surface. Couplants consist of liquids such as water, glycerin, light oil, or cellulose gum powder mixed with water. After examination, couplants must be completely removed with an acceptable solvent if heat is to be applied to the test surface at a later stage.

The weld metal or base metal must be smooth and flat to allow close contact with the search unit if required by the UT procedure. If the search unit is to be placed on the weld itself, removal of the weld reinforcement by grinding may be necessary. Weld spatter, slag, or other irregularities must be removed where the search unit might contact them.

UT Electronic Components. Electronic components required for UT include:

- An electronic signal generator to provide bursts of alternating voltage
- A sending transducer (crystal) to emit a beam of ultrasonic waves when the AC voltage is applied
- A receiving transducer to convert the sound waves to AC voltage (the receiving transducer and the sending transducer may be combined).
- An electronic device to amplify and demodulate or otherwise change the signal from the receiving transducer
- An electronic timer to control the operation
- A CRT display to characterize or record the output from the test piece. The CRT display uses A-scan presentation. See Figure 32-17.

UT Electronic Components
Figure 32-17

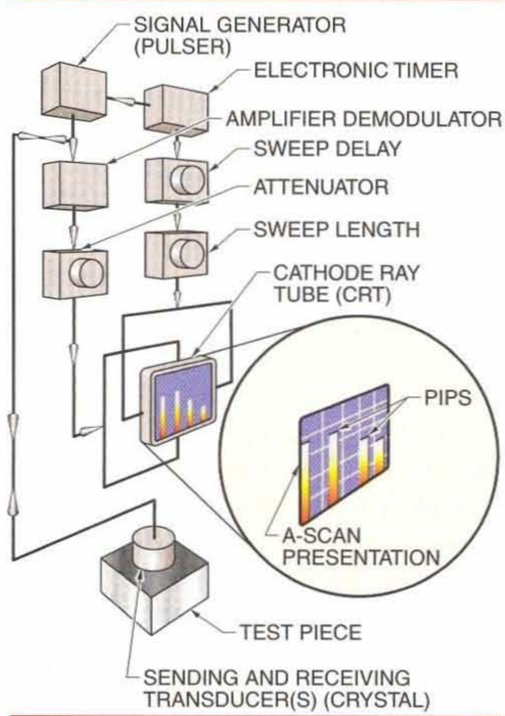


Figure 32-17. *The basic equipment components required for UT are a signal generator, sending and receiving transducers, an amplifier/demodulator, a CRT display, and an electronic timer.*

A-scan presentation is a method of data presentation using a horizontal base line that indicates distance or time, and a vertical deflection from the base line that indicates relative amplitude of the returning signal. The screen is graduated in both horizontal and vertical directions to facilitate measurement of pulse displays.

Ultrasonic Waves. Ultrasonic waves (vibrations) can be passed through particles that make up liquids, solids, and gases. Ultrasonic waves are above the audible range, with frequencies of about 22.5 kHz and higher. Ultrasonic waves used in weld testing are longitudinal waves and shear waves. See Figure 32-18.

Ultrasonic Waves
Figure 32-18

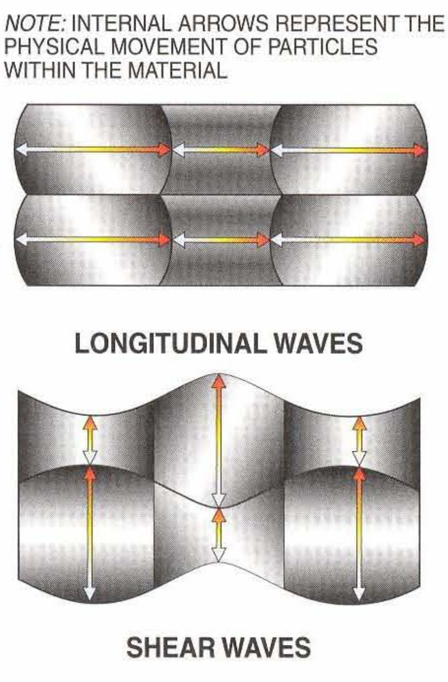


Figure 32-18. *Longitudinal waves and shear waves are typically used for ultrasonic weld testing.*

A *longitudinal wave* is a compression wave that represents wave motion in which the particle oscillation is in the same direction as wave propagation. Longitudinal waves can travel through solids, liquids, and gases.

A *shear wave* is a transverse wave that represents wave motion in which the particle oscillation is perpendicular to wave propagation direction. Shear waves are more easily dispersed than longitudinal waves and only travel through solids, since they cannot be propagated in liquids or gases. Shear waves have a lower velocity that allows easier electronic timing and greater sensitivity to small indications.

Shear waves are more effective than longitudinal waves at detecting weld discontinuities because they can furnish three-dimensional coordinates for discontinuity location, orientation, and characteristics. Shear wave sensitivity is about double longitudinal wave sensitivity for the same frequency and search unit size.

Longitudinal waves and shear waves complement one another in weld testing. The base metal zones adjacent to a weld are first tested with longitudinal waves to ensure that the base metal does not contain discontinuities that would interfere with shear wave evaluation of the weld.

Amplifier controls include amplification control (sensitivity, gain, and uncalibrated gain), attenuation (attenuator, calibrated gain), frequency control (frequency, MHz), and display control (display control, rectified trace, unrectified trace, B-scan trace).

Ultrasonic Examination Procedure Requirements

UT procedure requirements define how the instrumentation is set up and used for weld testing. UT procedure requirements for weld testing consist of pulse-echo mode, amplifier controls, calibration standards, and instrument calibration procedures.

Pulse-Echo Mode. *Pulse-echo mode* is a UT examination in which the presence and position of a reflector are

Ultrasonic waves used in weld testing are longitudinal waves and shear waves.

indicated by the echo amplitude and time. The pulse-echo mode produces repeated bursts of high-frequency sound from the crystal with a time interval between bursts to receive signals from the test piece and from any discontinuities in the weld or base metal. Each pulse sets off a wave of mechanical vibrations. The initial distortion and subsequent vibrations of the crystal are fed to the amplifier and cause a pip on the CRT.

The ultrasonic unit senses reflected impulses, amplifies them, and presents them as spikes, called pips, on the CRT. The horizontal location of a reflector pip on the screen, such as from a flaw, is proportional to the distance the sound has traveled in the test piece. This makes it possible to determine the location of reflectors such as flaws by using horizontal screen graduations as a distance-measuring ruler.

Calibration Standards. Reliable information can be obtained about the specimen on the CRT by comparing signals from the specimen with those obtained from specially machined blocks, known as calibration standards. A *calibration standard* is a calibration block or a reference block.

A *calibration block* is a piece of material of specified composition, heat treatment, geometric form, and surface finish, by which ultrasonic equipment can be assessed and calibrated for the examination of material of the same general condition. A calibration block may be a simple step wedge of a particular material to allow the time base to be calibrated for accurate thickness measurement. A calibration block may also be a more complex block, allowing calibration of time base, search unit angle, resolution, index, and other features. A *reference block* is a test piece of the same material, shape, and significant dimensions as a particular object under examination, and which may contain natural or artificial discontinuities or defects.

Ultrasonic Examination Methods

Applicable standards for UT of welds are detailed in ASTM E164, *Standard Practice for Ultrasonic Contact Examination of Weldments.* The standard covers examination of specific weld configurations in wrought ferrous and aluminum alloys to detect weld discontinuities. Recommended procedures for testing butt, corner, and T-joints are given for weld test piece thicknesses from .5″ to 8″. Required procedures for calibrating equipment and appropriate calibration blocks are included in the standard.

UT of Base Metal. UT of the base metal is done on either side of the weld over a band that extends as far as a full skip for the shallowest angle probe, usually a 70° probe, plus half the weld reinforcement width. A *full skip* is one complete reflection of the ultrasonic beam. By checking the base metal thickness, actual thickness values are obtained for subsequent shear wave calibrations rather than the nominal thickness obtained from the prints.

Systematic scanning of base metal in the band where subsequent shear wave scans will be made allows detection of laminations, which, although they may not affect the strength of the structure, might interfere with the shear wave beam. A large lamination causes the beam to reflect up to the weld reinforcement, giving a signal that might be mistaken for a normal root bead. At the same time, the lamination can cause the beam to miss a discontinuity such as lack of penetration.

UT of Root Pass. UT of the root pass is carried out from both sides of the weld, whenever possible, using a suitable angled probe. UT of the root pass detects incomplete penetration or incomplete fusion. Scanning lines are marked at half skip distance back from the original root face on either side of

the weld. A guide is then placed so that when the heel of the selected angle probe is butted against the guide, the probe index is on the scanning line. Flexible magnetic strips are useful guides for magnetic materials such as steel. See Figure 32-19.

Ultrasonic Examination of Root Pass
Figure 32-19

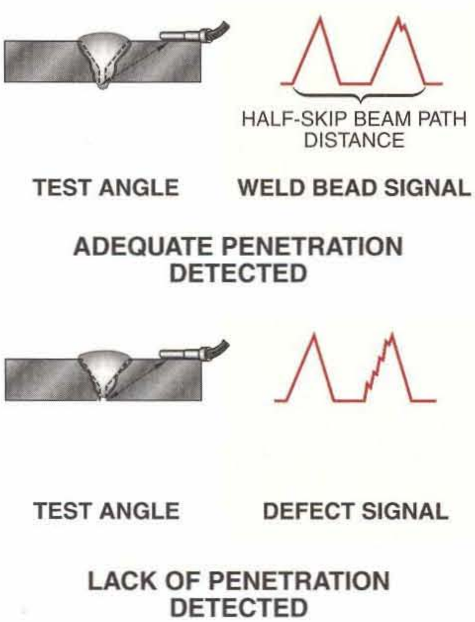


Figure 32-19. *UT of the weld root is carried out using an angled probe and is performed from both sides of the weld whenever possible.*

Ultrasonic Examination of Fusion Face and Weld Body. Ultrasonic examination of the fusion face and the weld body requires examining the entire weld volume. The probe is positioned to produce full skip distance to the nearest edge of the weld reinforcement. The probe index is located at a distance from the weld centerline equal to full skip distance plus one-half the full weld reinforcement width. The base metal is marked with two lines, parallel to the weld centerline, on both sides of the weld. The lines are at half skip and full skip distances and mark the boundaries of the scanning pattern. See Figure 32-20.

Ultrasonic Examination of Fusion Face and Weld Body
Figure 32-20

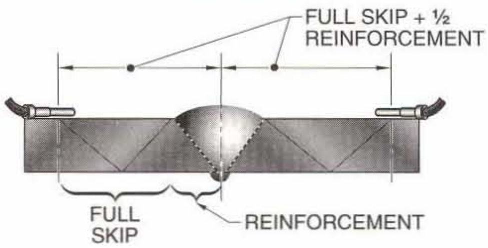


Figure 32-20. *UT of the fusion face and the weld body consists of examining the entire weld volume, which is a full skip distance plus one-half the weld reinforcement width.*

The initial probe angle for the weld body scan depends upon the weld bevel angle. For maximum response, the probe angle selected should meet any sidewall lack of fusion at right angles. The required angle is calculated by dividing the weld bevel angle by 2 and subtracting from 90°. For a weld bevel angle of 60° the probe angle is 60° ($90 - {}^{60}/_{2} = 60$).

Recording Ultrasonic Examination Results

Recording of UT results consists of documenting the inspection background, equipment used, equipment calibration, UT technique, and results.

RADIOGRAPHIC EXAMINATION (RT)

Radiographic examination (RT) is the use of X rays or nuclear radiation (gamma rays) to detect various types of internal and external discontinuities in material. RT images are presented on a recording medium. RT requires a source of radiation, a recording device enclosed in a light-tight holder, a qualified radiographer to produce a satisfactory exposure, and an examiner qualified to interpret radiographs. RT is used extensively to examine welds for internal discontinuities by exposing them to penetrating radiation.

When performing RT in the field, most operations must be shut down until RT is completed. For this reason, RT is commonly performed at night or on weekends when fewer personnel will be affected.

Radiographic Examination Principles

X rays and gamma rays are two types of electromagnetic waves used to penetrate opaque materials. A permanent record of the internal structure is obtained by placing a sensitized film in direct contact with the back of the weldment. When the X or gamma rays pass through a weldment of uniform thickness and structure, they fall upon the sensitized film and produce a negative of uniform density. If the weldment contains gas pockets, slag inclusions, or cracks or has a lack of penetration, more rays will pass through the less dense areas and will register on the film as dark areas, clearly outlining the defects and showing their size, shape, and location. RT principles are governed by penetration and absorption, radiographic image quality, RT personnel, and radiation safety.

Radiographic film is placed on the opposite side of the test specimen to record the internal image of the component.

A *radiograph* is a permanent, visible image on a recording medium produced by penetrating radiation passing through a material being tested. See Figure 32-21.

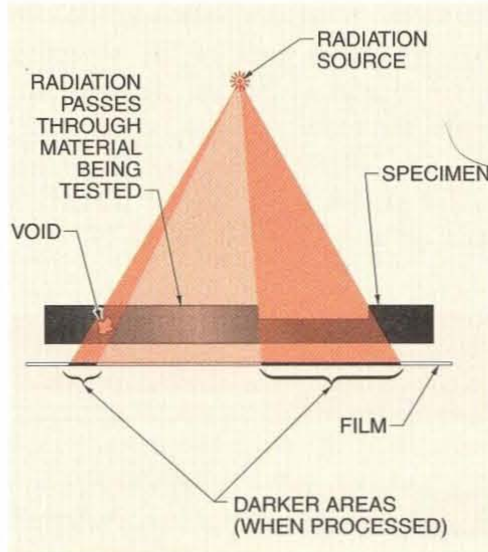
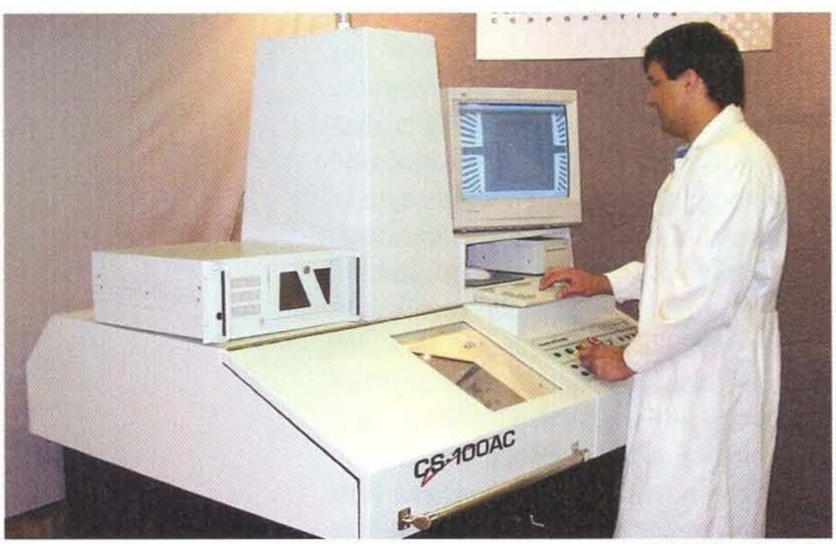


Figure 32-21. *The test material absorbs radiation, but less absorption takes place where there is a void, leading to darker areas on the processed radiograph.*

Radiographic film is placed on the opposite side of the test specimen to record the internal image of the component. The recording medium can be photographic film, sensitized paper, a fluorescent screen, or an electronic radiation detector. Photographic film is the most commonly used method.

Since more radiation passes through thin sections or locations containing voids, the corresponding areas of the film are darker. The relative positioning of the source and film in relation to the part or weld affects the sharpness, density, and contrast of the radiograph. The radiograph image quality is affected by image enlargement, image sharpness, and image distortion.

Image distortion occurs when the plane of the part and the plane of the film are not parallel. To minimize image distortion, the radiation beam must be directed in a direction perpendicular to the plane of the film. If distortion of the film image is unavoidable, the radiographer must take into consideration that all parts of the image are distorted; otherwise, the radiograph may be incorrectly interpreted. See Figure 32-22.



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The radiographer must consider all parts of the image, including areas that may be unavoidably distorted, to ensure correct interpretation of the radiograph.

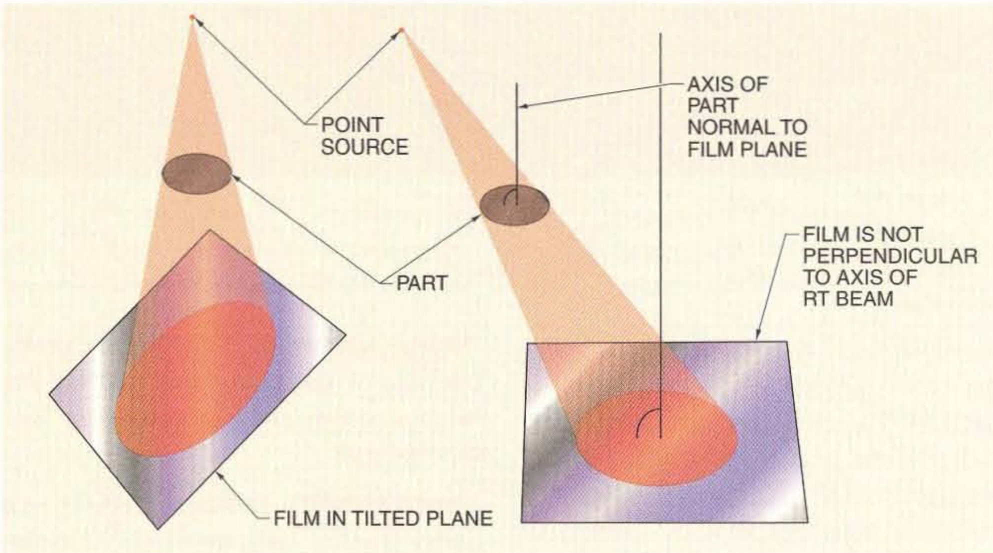

Figure 32-22. *Image distortion occurs when the plane of the film is not perpendicular to the radiation beam.*

Radiographic Examination Procedure

Radiographic examination procedure requirements are necessary to ensure the correct application of RT for weld examination. RT procedure requirements may be influenced by applicable codes and standards. RT requirements are governed by radiation source type, isotope camera, intensifying screens and filters, image quality indicator, lead identification markers, film type and film processing method.

Radiation Source Types. Radiation sources for weld inspection may be X rays from X-ray machines and gamma rays from radioactive isotopes. Both types have extremely short wavelengths, enabling them to penetrate materials that absorb or reflect light. Although the wavelength and radiation produced can be quite different, both X and gamma rays behave similarly for RT purposes.

The wavelengths of X radiation are determined by the voltage applied between the elements of an X-ray tube. Higher voltages produce X rays of shorter wavelengths and increased intensities, resulting in deeper penetration capability. The penetrating ability of X rays depends on the X-ray absorption properties of the particular metal. See Figure 32-23.

STEEL THICKNESS LIMITATIONS FOR X-RAY MACHINES

Maximum Voltage*	Maximum Steel Thickness†	
	in.	mm
100	.33	8
150	.75	19
200	1	25
250	2	50
400	3	75
1000	5	125
2000	8	200

* in KV
† approximate

Figure 32-23. *The penetrability of X rays from the X-ray machine into the part depends on the voltage applied across the elements of the X-ray tube. Maximum voltages are established based on the thickness of the metal to be tested.*

Gamma rays are produced from portable sources and are used extensively for field-testing of welds. The gamma ray source is made as small as possible in the shape of a cylinder whose diameter and length are approximately equal. The cylindrical shape permits the use of any surface of the source as the focal spot since all surfaces, as viewed from the test specimen, are equal in area. The wavelength of the gamma rays (energy level) is determined by the nature of the source. Gamma rays have different ranges of energy and different thickness limitations for materials examined. See Figure 32-24.

Figure 32-24. *Radioisotopes have different ranges of energy, making them suitable for different thicknesses of metals.*

STEEL THICKNESS LIMITATIONS FOR RADIOISOTOPES			
Radioisotope	Equivalent X-Ray Machine kV*	Maximum Steel Thickness*	
		in.	mm
Iridium-192	800	.5–2.5	12–65
Cesium-137	1000	.5–3.5	12–90
Cobalt-60	2000	2–9	50–230

* approximate

Iridium-192 is equivalent to the output of an 800 kV X-ray machine. It is used for the radiography of steel. The radioisotope is supplied in the form of a capsule. The relatively low-energy radiation and high specific gravity of iridium-192 combine to make it an easily shielded, strong radiation source with a small focal spot size.

Cesium-137 is equivalent to the output of a 1000 kV X-ray machine. The radioisotope is supplied in the form of a capsule and is used on a limited scale for low-density metals such as aluminum.

Cobalt-60 is equivalent to the output of a 2000 kV X-ray machine. Cobalt-60 is used for the radiography of steel, copper, brass, and other medium-density metals. Because of its penetrating radiation, cobalt-60 requires thick shielding with resulting weight and handling difficulty.

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The results of radiographic testing are downloaded to a computer for storage and future reference.

Isotope Camera. The isotope camera consists of the equipment needed for safe handling and storage of an isotope source.

Image Quality Indicator (IQI). An *image quality indicator (IQI)* is a device or combination of devices whose demonstrated image determines radiographic quality and sensitivity. The image or images demonstrated by an IQI provide visual data, quantitative data, or both to determine the radiographic quality. An IQI is not intended for use in judging size of, or acceptable limits for, discontinuities. An IQI is also called a penetrameter, or penny. Each IQI is identified by an identification number that gives the maximum thickness of material for which the IQI is normally used. See Figure 32-25.

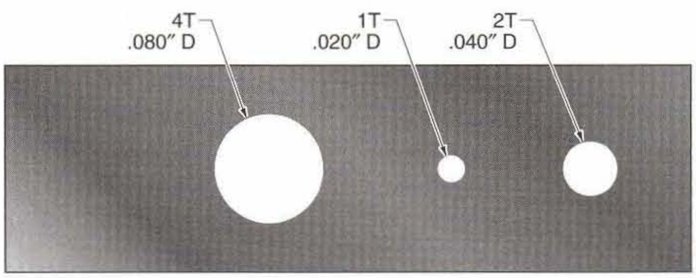
The IQI is placed on the source side of the part to provide a built-in discontinuity of known thickness containing three hole diameters. The IQI measures the ability of the RT technique to show contrast (IQI thickness) and definition (hole images).

Shim stock is sometimes used in RT of welds because the area of interest (the weld) is thicker than the part thickness. Shims are selected so that the thickness of the shim(s) equals the thickness added to the specimen by the weld in the area of interest. Shim stock is placed underneath the IQI, between it and the part. In this way, the image of the IQI is projected through a thickness of material equal to the thickness in the area of interest. The shim stock length and width are greater than those of the IQI. See Figure 32-26.

IMAGE QUALITY INDICATOR (IQI) SIZES					
Applies to Design Material Thickness* (T_m) up to and including inches†	ID No.	"T"‡	1T Hole Diameter†	2T Hole Diameter†	4T Hole Diameter†
¼ (.25)	25	.005	.010§	.020§	.040§
⅜ (.375)	37	.008	.010§	.020§	.040§
½ (.5)	50	.010	.010	.020	.040
⅝ (.625)	62	.013	.013	.025	.050
¾ (.75)	75	.015	.015	.030	.060
⅞ (.875)	87	.018	.018	.035	.070
1 (1)	1	.020	.020	.040	.080
1⅛ (1.125)	1.1	.023	.023	.045	.090
1¼ (1.25)	1.2	.025	.025	.050	.100
1½ (1.5)	1.5	.030	.030	.060	.120

* Defined as the thickness of the material (T_m) upon which the thickness of the IQI is based. For welds, T_m shall be the thickness of the strength member
† in in.
‡ IQI thickness
§ Hole size required by standard does not correspond directly to ID number or IQI thickness

NOTES:
Chart extends in ¼″ increments up to 2½″, then in ½″ increments up to 8″, and then in 1″ increments.



STANDARD IQI FOR 1″ MATERIAL

Figure 32-25. *An image quality indicator (IQI), or penetrameter, determines the radiographic quality level (sensitivity). The IQI thickness ("T") is 2% of the thickness of the part being radiographed.*

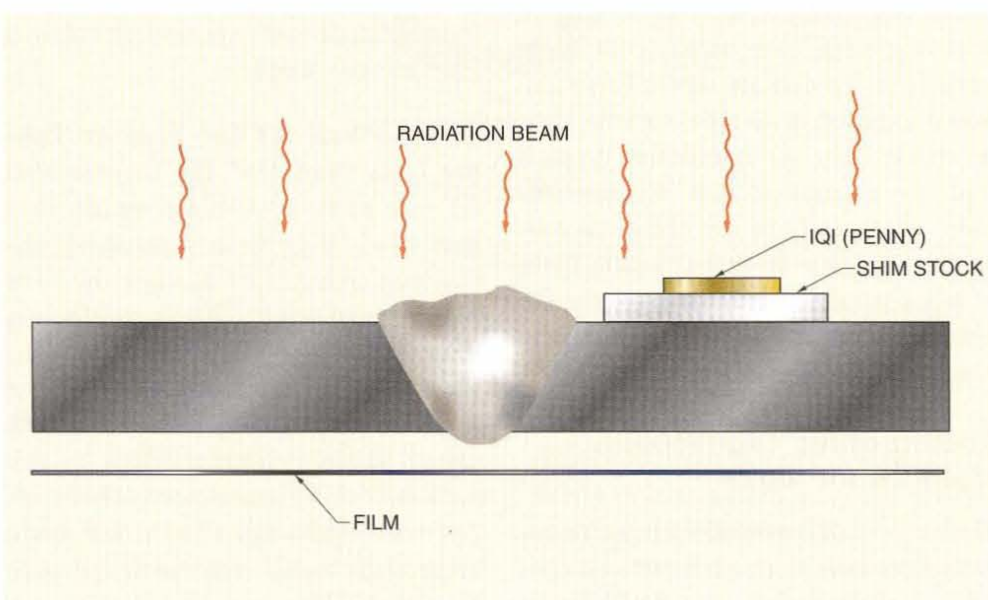
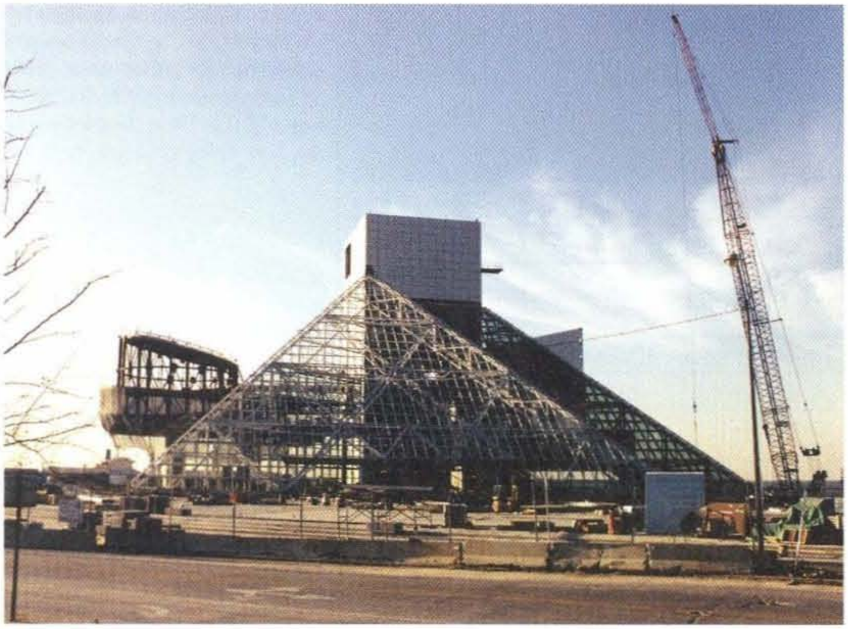


Figure 32-26. *Shim stock may be used to compensate for the additional thickness of a weld compared with the base metal.*



The Lincoln Electric Company

Nondestructive examination is often used for structures that must remain in service both during and after testing.

Lead Identification Markers. Lead identification markers are placed on the source side of the part to provide a clear record of the test or test location. These markers consist of a letter and numbers and must not interfere with subsequent interpretation of the radiograph by masking potential indications.

Film Type. The film type selected is based on the need for radiographs of specific contrast and definition quality. RT film consists of thin, transparent plastic sheeting coated on one or both sides with an emulsion of gelatin, approximately .001" thick, containing very fine crystals of silver bromide. When exposed to X rays, gamma rays, or visible light, silver bromide crystals undergo a reaction that makes them more susceptible to the chemical process of developing that converts them to black-metallic silver. The greater the amount of exposure, the greater the blackening effect on development.

Radiographic Examination Methods for Welds

Selection of RT methods for welds requires consideration of how the exposure can be set up for the type of part. Some RT methods for welds include single-wall RT for plate, pipe, or tubing; double-wall RT for pipe or tubing less than 1¼″ ID (inside diameter); and double-wall RT for pipe or tubing from 1¼″ to 2½″ ID.

RT exposure setup conditions are based on the following factors that influence the radiographic image formation:

- Obtaining best coverage of the weld in the shortest exposure time
- Detecting image discontinuities most likely to be present
- Using multiple perpendicular exposures rather than one or more angled exposures to cover all areas of interest
- Using single- or double-wall exposures with a pipe weld
- Adhering to all radiation safety requirements

Single-Wall RT for Plate and Pipe or Tubing. Single-wall RT for plate, pipe, or tubing welds is relatively simple to achieve because the critical areas of the weld are clearly defined in terms of their length, width, and thickness. See Figure 32-27. The film is placed in direct contact with the part on the side opposite to the source with an exposure angle of 90°. Single-wall RT should be used whenever possible for flat or circular objects. Subject contrast is small and exposure calculation is relatively simple.

Double-Wall RT for Pipe or Tubing Less than 1¼″ ID. Double-wall RT for pipe or tubing welds less than 1¼″ ID is done with an elliptical shot. An elliptical shot involves placing the source at an angle less than 90° to the plane of the part to view the full circumference of the weld on the film as an ellipse. The exact angle is determined by the pipe or tubing diameter. Three elliptical exposures should be made to provide sufficient coverage. See Figure 32-28.

Single-Wall Radiographic Examination
Figure 32-27

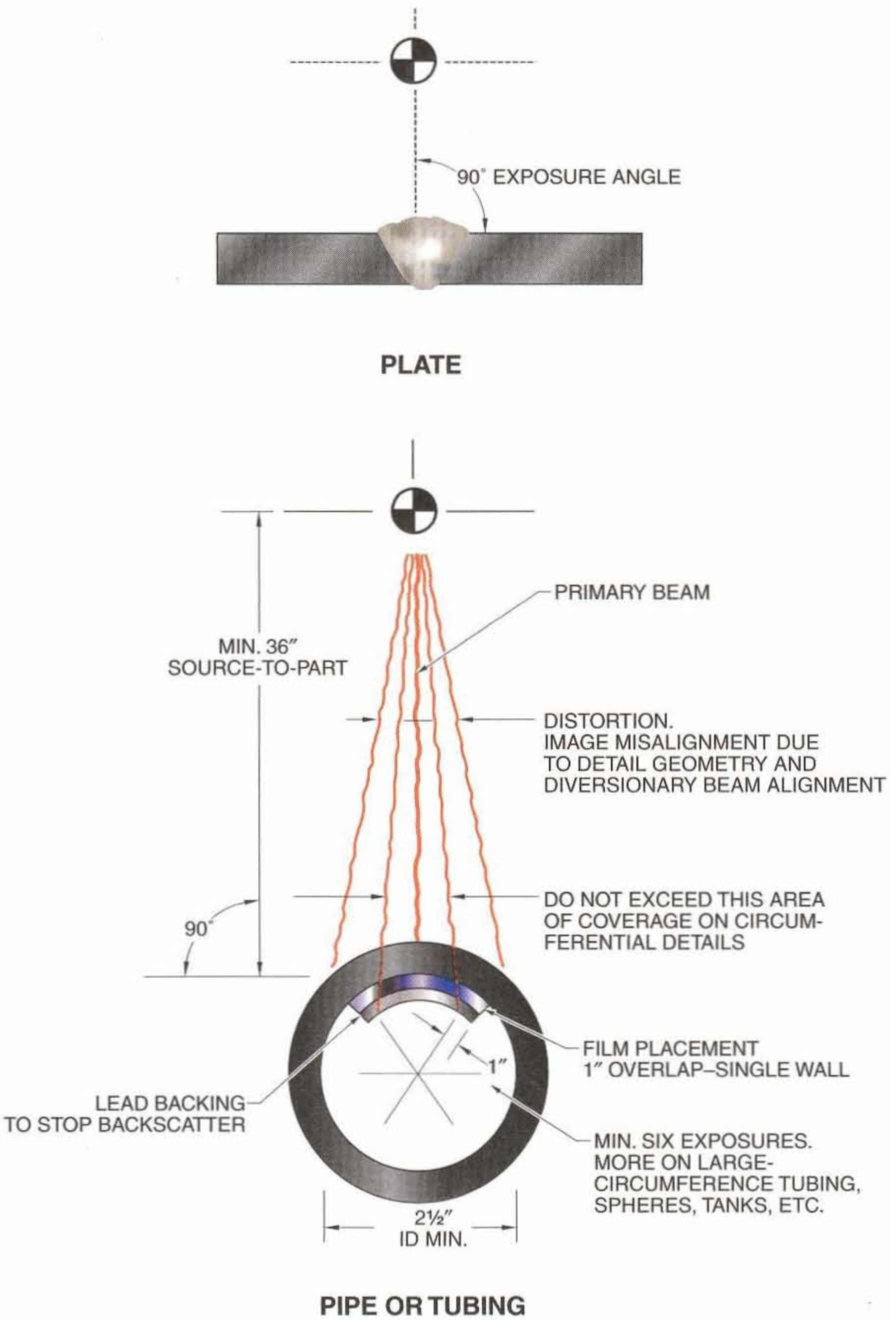


Figure 32-27. *Single-wall RT for plate, pipe, or tubing is relatively easy to achieve because the critical areas of the weld are clearly defined.*

Double-Wall RT for Pipe or Tubing 1¼″ to 2½″ ID. Double-wall RT for pipe or tubing welds from 1¼″ to 2½″ ID is done with a 15° elliptical shot. As with pipe or tubing less than 1¼″ diameter, two IQIs should be used. Six elliptical shots provide sufficient coverage of the entire circumference and reveal discontinuity orientation. In addition, two 90° opposing, superimposed shots should be taken to show discontinuities in the perpendicular position. See Figure 32-29.

Double-Wall Radiographic Examination for Pipe and Tubing Less Than 1¼″ ID
Figure 32-28

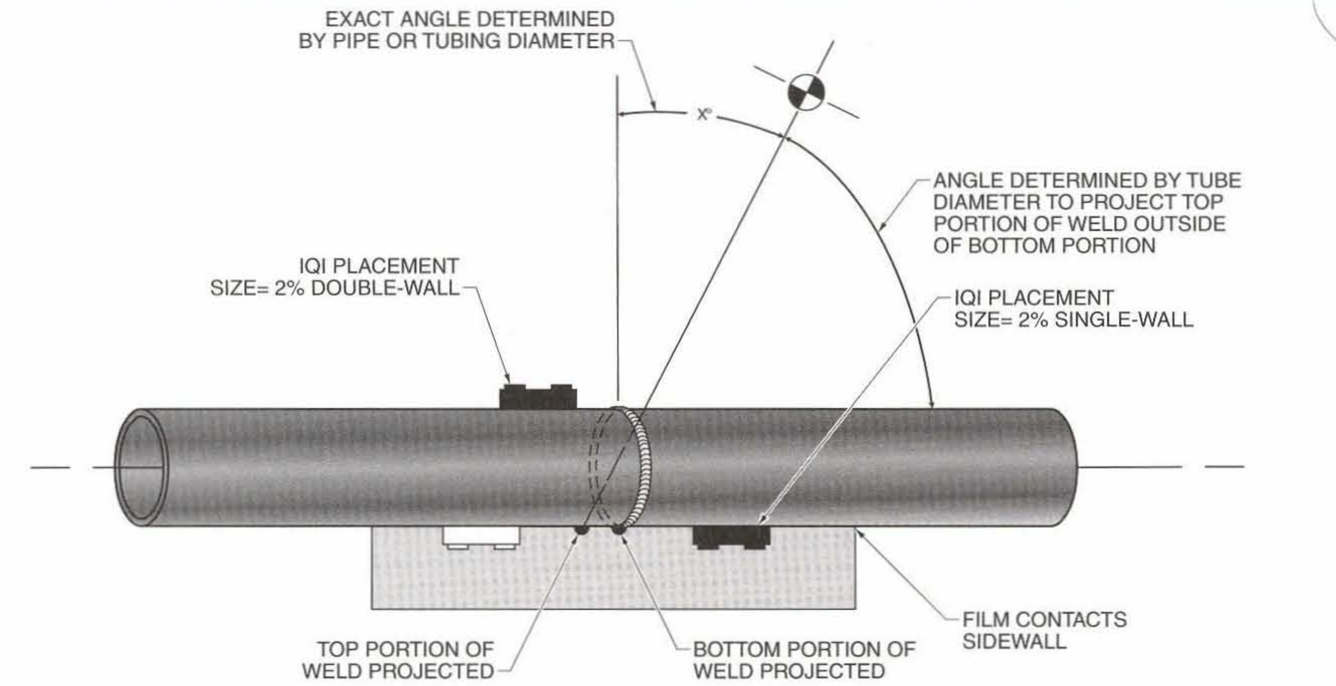


Figure 32-28. *The source angle for double-wall RT of pipe or tubing less than 1¼″ ID is determined by the pipe or tubing ID to ensure the top portion of the weld projects outside of the bottom portion.*

Double-Wall Radiographic Examination for Pipe and Tubing 1¼″ ID to 2½″ ID
Figure 32-29

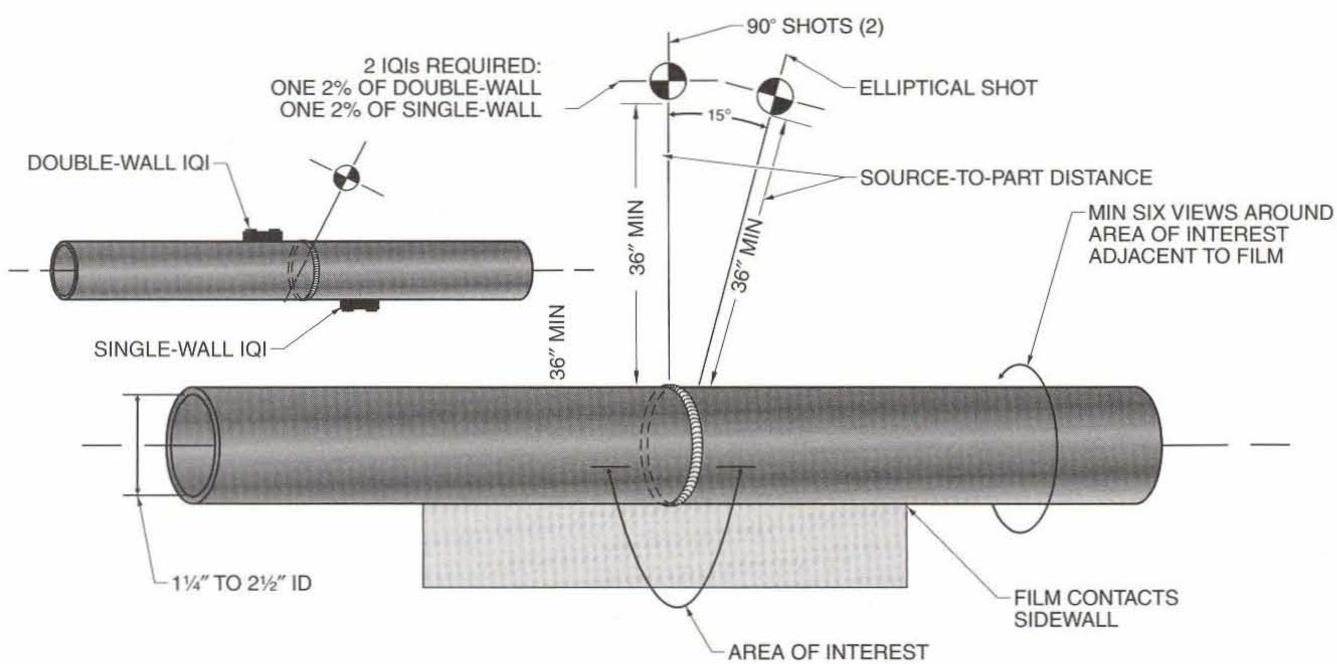


Figure 32-29. *RT of pipe or tubing from 1¼″ to 2½″ ID requires a 15° elliptical shot and two 90° shots.*

To evaluate a radiograph, follow the procedure:

1. Compare the identification of the radiograph against accompanying records for accuracy.
2. Determine the weld design and welding procedure used.
3. Determine the radiographic set-up procedure and the correctness of technique attributes.
4. Review film under optimum viewing conditions.
5. Identify any film artifacts (see below) and request re-radiography if necessary.
6. Identify any surface marks or unsoundness on the part not associated with the weld and verify their type and presence.
7. Evaluate and propose disposition of discontinuities revealed in the radiograph.
8. Prepare complete radiographic report.

RT for fillet welds is difficult to set up and interpret. Fillet weld RT requires a great degree of skill and in-depth knowledge of the welding conditions. Also, it is difficult to place the film ideally to obtain good resolution of discontinuities in fillet welds. Therefore, RT is not usually viable For fillet welds.

Identification of Discontinuities

RT reveals both surface and subsurface weld discontinuities including cracks and incomplete fusion; slag inclusions and tungsten inclusions; porosity and wormholes; incomplete joint penetration; undercut; excessive weld reinforcement; and insufficient weld reinforcement. RT does not reveal very narrow discontinuities that are not closely aligned (parallel) to the weld.

Cracks appear as fine dark lines of significant length, but without great width. Some crater cracks may be detected by RT if of sufficient size. Cracks may not be detected if they are small or not aligned with the beam.

Incomplete fusion has a similar appearance to cracks, but usually appears at the boundary between the weld and base metal.

Slag inclusions usually appear as irregularly shaped dark areas and have some width. Slag inclusions are generally observed at the junctions between weld passes. Tungsten inclusions appear as highly contrasted light areas (white spots).

Porosity appears as nearly round voids recognizable as dark spots whose radiographic contrast varies directly with the diameter of the pores.

Wormholes appear as dark rectangles if their long axis is perpendicular to the beam and as concentric circles if the long axis is parallel to the beam.

Incomplete joint penetration is observed as a very narrow dark line near the center of the weld.

Undercut appears as a dark zone of varying width along the edge of the fusion zone. The darkness or density of the line is an indicator of the depth of the undercut.

Excessive weld reinforcement is seen as a lighter zone along the center of the weld seam. There is a sharp change in image density where the reinforcement meets the base metal, and the edge of the reinforcement image is usually irregular.

Insufficient weld reinforcement is seen as the opposite of excessive weld reinforcement, that is, a darker zone along the center of the weld seam. The change in image density is not as pronounced as with excessive weld reinforcement.

Artifacts. An *artifact* is a nonrelevant indication that appears on a radiograph. Artifacts may occur during exposure or during handling or processing of the film, if handling or processing has been done improperly. Artifacts also may occur because of various causes including electrostatic discharge, pressure marks, and film processing defects. Artifacts must be avoided.

Electrostatic discharge during film handling exposes the film to light and causes an easily recognized pattern of sharp black lines on the radiograph. Pressure marks result from localized pressure on pre-processed film when the film is being processed.

Film processing defects lead to many kinds of artifacts. Colored stains or blisters may result from an improper acid stop bath application. Streaks may result from improper agitation during development. Fogging may be caused by overexposure of film to a safelight lamp before fixing or by using old film. Stains may be caused by improperly mixed or exhausted solutions, and water marks can result from handling partially dried film. Fingerprints are caused by improper handling of film. Scratches result from rough handling, especially during processing when the emulsion is soft. Chemical fog may be caused by overdeveloping.

Recording Radiographic Examination Results

Recording of RT results is done on a form consisting of a sketch identifying the weld locations, a description of the RT method used, and identification and interpretation of all discontinuities. RT results may be recorded in a standard format. The owner of the part tested shall retain radiographs related to the examination.

ELECTROMAGNETIC EXAMINATION (ET)

Electromagnetic examination (ET) is an NDE method that uses electromagnetic energy having frequencies less than visible light to yield information on the quality of the part being tested. ET, also called eddy current testing, uses electromagnetic energy to detect discontinuities in welds and is effective in testing both ferrous and nonferrous materials for porosity, slag inclusions, internal cracks, external cracks, and lack of fusion. ET is applied to both magnetic and nonmagnetic materials.

Electromagnetic energy is used to detect surface and internal quality of welds in electromagnetic testing.

Electromagnetic Examination Principles

Electromagnetic examination principles are based on the phenomenon of electromagnetic induction, meaning that an electric current flows, or is induced, in a conductor subject to a changing magnetic field. The frequency of the magnetic field varies from 50 Hz to 1 MHz, depending on the type and thickness of the materials tested. In weld testing, ET is used principally in automatic production testing of welded pipe and tube.

Electromagnetic Induction. Electromagnetic induction creates different responses in metals according to their electromagnetic properties. The part to be inspected is placed within or adjacent to an electric coil through which alternating current (the exciting current) is flowing. The exciting current induces a magnetic field and causes eddy currents to flow in the part because of electromagnetic induction. An *eddy current* is an electrical current caused to flow in a conductor by the time or space variation, or both, of an applied magnetic field. To achieve electromagnetic induction, the electric coil may be an encircling coil or an inside coil. See Figure 32-30.

Coils
Figure 32-30

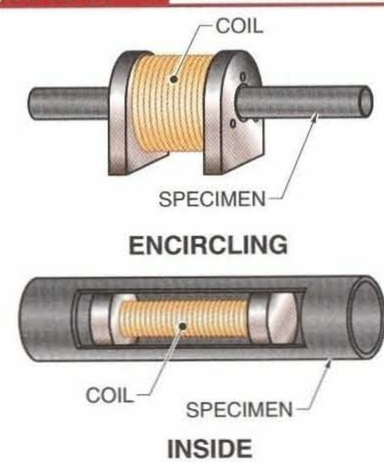


Figure 32-30. *Incomplete fusion may be detected in tubing as it passes through an encircling coil or an inside coil during electromagnetic examination.*

An encircling coil is wound so that the test specimen passes through the center of the coil, causing the eddy currents to flow around the rod or tube being tested. The specimen must be centered in the coil for accurate test results. This is because the flow of eddy currents is zero at the center of the rod. An inside coil is used to test steam generator tubes. Inside coils pass through the inside of tubing and eddy currents flow around the tubing. For accurate test results, the coil and the test specimen should be close together.

The eddy current path is distorted by the presence of a discontinuity. The distortion is measured by a change in the associated electromagnetic field. Such changes have an effect on the exciting coil or other coil(s) used for sensing the electromagnetic field adjacent to the part. For example, the change in flow of eddy currents caused by incomplete fusion can be detected as the tubing passes through the coil. When fusion within the weld is complete, the eddy current flow is symmetrical. As a section containing incomplete fusion passes through the coil, the eddy current flow is impeded and changed in direction, causing a significant change in the associated electromagnetic field, which is detected on the measuring equipment.

For electromagnetic examination, the induced voltage of the exciting coil or the adjacent coil is used to monitor the condition of the part being inspected.

Electromagnetic Examination Requirements

Electromagnetic examination requirements indicate the parameters that must be controlled and documented to ensure effective, repeatable applications. ET requirements include ET inspection equipment, ET equipment calibration, and ET procedures.

ET Inspection Equipment. ET inspection equipment consists of a generator, inspection coil, amplifier, detector, and display. The generator supplies excitation current to the inspection coil and a synchronizing signal to the phase shifter, which provides switching signals to the detector. The probe may be an external coil, as used for tubing inspection.

ET Equipment Calibration. An *equipment calibration standard* is a test piece that contains typical discontinuities that demonstrate that calibration equipment is detecting the discontinuities for which the part is being inspected. Equipment calibration standards for ET contain natural or artificial discontinuities. The discontinuities in the calibration standards can accurately reproduce the exact change in the electromagnetic characteristics expected when production items containing discontinuities are tested.

Equipment calibration standards are necessary because ET does not detect discontinuities, but rather the effect they have on the electromagnetic properties of the part being inspected. It is necessary to correlate the change in electromagnetic properties with the cause of the change. Equipment calibration standards are used to facilitate the initial adjustment or calibration of the test equipment and to periodically check on the reproducibility of the measurements.

ET Procedures. ET procedures reference the type of equipment calibration standards that are required. Electromagnetic examination procedures must be standardized, often using full-scale or mock-up calibration standards with simulated discontinuities. Equipment calibration standards must meet the following requirements:

- Conform to the applicable specification.
- Be easily fabricated.
- Be reproducible in precisely graduated sizes.
- Produce an indication on the ET tester that closely resembles those produced by natural discontinuities.

Electromagnetic examination procedures must be standardized, often using full-scale or mock-up calibration standards with simulated discontinuities.

Proof testing is used to demonstrate the ability of the welded structure to carry loads equal to or in excess of the anticipated service conditions.

Electromagnetic Examination Methods for Welds

Electromagnetic examination methods for welds are primarily applied to longitudinal welded pipe or tubing as a production quality control tool.

ET of Longitudinally Welded Pipe or Tubing. ET of longitudinally welded pipe or tubing is done using an encircling external energizing coil and a probe-type differential detector coil. The probe-type detector coil is located at the longitudinal center in the inner perimeter of the primary coil and is arranged so that it inspects the outside surface of the longitudinal weld.

Examination is performed by passing the pipe or tubing longitudinally through the primary energizing coil, causing the probe-type detector coil to move across the longitudinal weld from end to end. The primary coil is energized with an alternating frequency that is suitable for the part being inspected and induces eddy currents into the part. See Figure 32-31.

Rath Manufacturing

Figure 32-31. *To inspect longitudinal weld quality in welded pipe or tubing, an energizing coil and a detector coil are required.*

The DC coil is energized at high current levels to magnetically saturate the pipe or tubing, improving penetration of the eddy current and canceling the effects of magnetic variables. This type of inspection is effective in detecting most types of longitudinal weld discontinuities, such as open welds, weld cracks, and hot cracks. Many discontinuities may be detected at relatively high speeds (speeds of 300 ft/min are common). The speed must be constant to within ±10%.

PROOF TESTING

Proof testing is the application of specific loads to welded structures, without failure or permanent deformation, to assess their mechanical integrity. Proof tests are usually designed to subject parts to stresses exceeding those anticipated during service, but maintained below or at the specified yield strength of the metal. Proof testing is used to demonstrate the ability of the welded structure to carry loads equal to or in excess of the anticipated service conditions. Proof tests must be designed by an engineer familiar with in-use requirements, and consist of hydrostatic testing, pneumatic testing, spin testing, leak testing, vacuum box testing, and acoustic emission testing.

Hydrostatic Testing

Hydrostatic testing (hydrotesting) is proof testing of closed containers such as vessels, tanks, and piping systems by filling them with water and applying a predetermined test pressure. Hydrostatic testing is the most common type of proof test.

Adequate venting must be ensured during hydrostatic testing to prevent collapse (sucking in) of the tank. See Figure 32-32. For components built to the ASME Boiler and Pressure Vessel Code, this pressure is 150% of design pressure. For other components, the test pressure may be based upon a fixed percentage of the minimum yield strength. After a fixed holding time, the container is inspected for soundness by visually checking for leakage, or by monitoring the hydrostatic test pressure for any drop.

Adequate venting must be ensured during hydrostatic testing to prevent collapse (sucking in) of the tank.

Open containers such as storage tanks may also be hydrostatically tested by filling them with water; ships or barges may be tested by partially submerging them in water. The hydrostatic pressure exerted against any boundary is governed by the head of water.

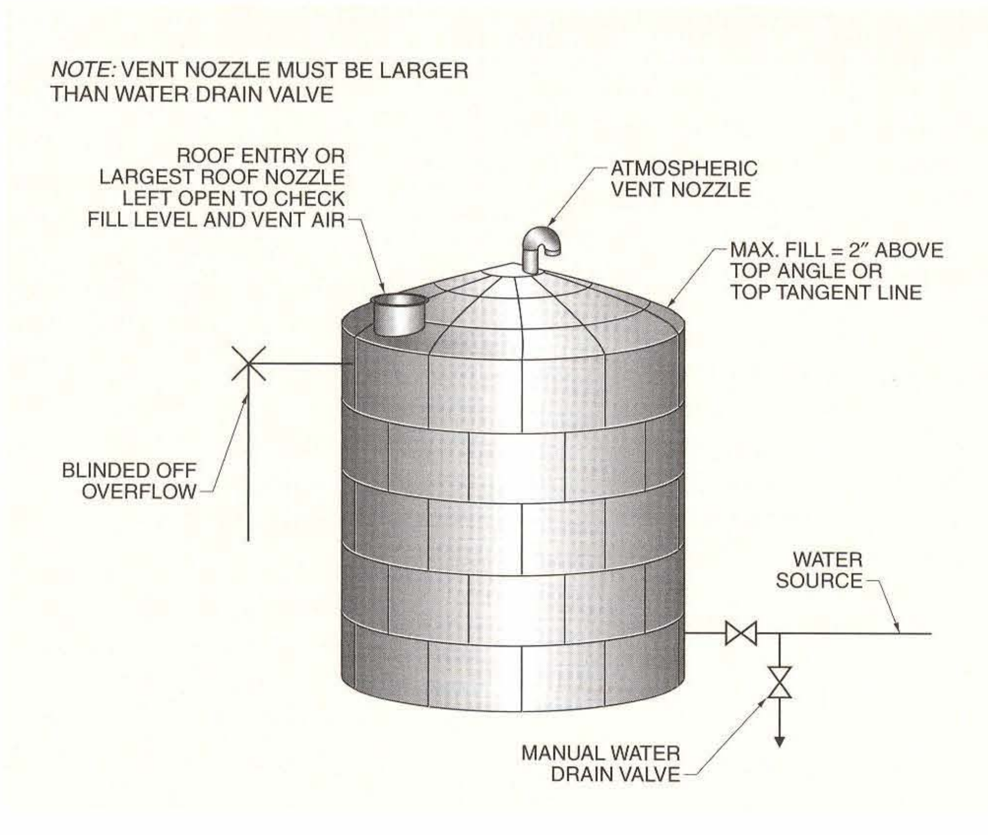


Figure 32-32. *When performing hydrostatic testing on an atmospheric pressure storage tank, there must be adequate venting to prevent the tank from collapse (sucking in) when it is drained.*

Three questions to consider before using hydrostatic testing are (1) whether the foundation or support is strong enough to hold the container filled with water, (2) whether energy in the form of compressed air can build up in the container, and (3) whether there is adequate notch toughness to ensure that small leaks or discontinuities will not propagate into a catastrophic failure.

Hydrostatic testing is a relatively safe operation because water is practically noncompressible and therefore stores little energy. A small leak results in meaningful pressure drop that limits the driving force available to propagate a crack.

Several important questions must be asked before hydrostatic testing is carried out to prevent permanent equipment damage or catastrophic failure. The following safety issues must be considered:

- Are the foundations and support structure strong enough to hold the water-filled container? This is especially important if the foundation and support container were originally designed to hold a gas or light-weight liquid.
- Are there any pockets where energy can build up in the form of a compressed gas? Pockets may include high points in the system that are difficult to completely fill with water.
- Is the water temperature above the ductile-brittle transition temperature of the steel or low-alloy steel? It may be necessary to warm the water slightly to assure that a relatively small leak or discontinuity will not propagate into a catastrophic brittle fracture.
- Is the water of sufficient purity to avoid rapid localized pitting of stainless steel? Fabrication codes and standards usually limit the chloride content of hydrotest water to ensure it is not damaging to stainless steels.
- Is the water drained and the equipment dried out completely after hydrostatic testing? This applies to

WARNING

During pneumatic testing, large amounts of energy may be stored in compressed air or gas in a large volume or under high pressure, or both. A small leak or rupture can easily grow into a catastrophic failure, and can endanger life and adjacent property.

stainless steel equipment where stagnant water may lead to microbiologically induced corrosion. Fabrication codes and standards usually allow a maximum time of 72 hr for water to be left in stainless steel equipment.

Pneumatic Testing

Pneumatic testing must be used with care to prevent a catastrophic failure caused by release of the stored energy.

Pneumatic testing is a proof test in which air is pressurized inside a closed vessel to reveal leaks. Pneumatic testing must be used with care to prevent a catastrophic failure from release of the stored energy. Pneumatic testing is usually performed on small units that can be submerged in water during testing. The presence of air bubbles is a convenient leak indicator and immersion in water is an effective energy absorber in case the component fails.

Pneumatic testing may be applied to equipment such as equipment mounted on foundations not able to support the weight associated with hydrostatic tests, and to equipment where water or liquid may be harmful and cannot be removed, for example a plate-fin heat exchanger.

Pneumatic testing acceptance is based on freedom from leakage. Small leaks are seldom detected without some indicating devices. If a unit cannot be submerged in water, spraying it with a soap or detergent solution and checking for bubbles is an effective alternative for determining the location of leaks. This procedure is called an air-soap test.

If both pneumatic testing and hydrostatic testing are to be done, the pneumatic test should be carried out first. If done in reverse order, there is a possibility that the larger water molecules from the hydrostatic test will locate and block fine leak passages and prevent them being discovered by the smaller air molecules during the pneumatic test.

Spin Testing

Spin testing is proof testing of rotating machinery done by spinning it at speeds above design values to develop desired stresses from centrifugal forces. Visual and other nondestructive testing plus dimensional measurements are employed to determine the acceptability of the parts. Spin testing is conducted in a safe enclosure such as a specially constructed pit in case the component should rupture.

Vacuum Box Testing

Vacuum box testing is the application of a partial vacuum to one side of a structure and examining for the presence of leaks. The test involves applying soap or detergent solution to an area such as a longitudinal weld, placing a transparent box with an adequate seal over the area to be examined, and evacuating the box to achieve partial vacuum of not less than 2 psi. The area is examined for bubbles, which are the sign of a leak. Vacuum box testing is quick and convenient.

Acoustic Emission Testing

Acoustic emission testing (AE) is a proof test that consists of detecting acoustic signals produced by plastic deformation or crack formation during mechanical loading or thermal stressing of metals. Transducers strategically placed on a structure are activated by arriving acoustic signals and allow the locations of discontinuities to be identified. Once the discontinuity location is identified, it must be examined by other techniques such as RT or UT to describe and measure it.

POINTS TO REMEMBER

1. A flaw is not necessarily a defect. A flaw may be relevant (requiring evaluation by nondestructive testing), nonrelevant (rejection is not necessary after evaluation), or false (no discontinuity actually exists).
2. Nondestructive examination is performed by an examiner, who is a person qualified to conduct specific NDE processes.
3. An inspector is a person qualified to interpret nondestructive examination results according to the controlling code or standard for the job.
4. Common nondestructive examination methods are visual, liquid penetrant, magnetic particle, ultrasonic, radiographic, and electromagnetic.
5. Visual examination is used to check surface condition; alignment of mating surfaces; conformance of the weld shape to a specific code or standard; and to locate leakage. Visual examination may be used before, during, or after welding.
6. Liquid penetrant examination is used to detect defects open to the surface, particularly in nonferrous metals such as aluminum.
7. The surface of a part must be completely clean and dry before administering liquid penetrant examination.
8. Magnetic particle examination is used to detect surface or near-surface discontinuity indications in ferromagnetic metals.
9. A magnetic field may be induced in a part by circular magnetization or longitudinal magnetization.
10. Magnetic powder may be applied by the dry magnetization method or the wet magnetization method.
11. Demagnetization is mandatory for parts in critical service, such as engines and aircraft, that have been strongly magnetized. Filings, grindings, and chips resulting from operational wear are attracted to magnetized parts and interfere with performance.
12. Ultrasonic waves used in weld testing are longitudinal waves and shear waves.
13. Radiographic film is placed on the opposite side of the test specimen to record the internal image of the component.
14. Electromagnetic energy is used to detect surface and internal quality of welds in electromagnetic examination.
15. Electromagnetic testing procedures must be standardized, often using full-scale or mock-up calibration standards with simulated discontinuities.
16. Proof testing is used to demonstrate the ability of the welded structure to carry loads equal to or in excess of the anticipated service conditions.
17. Adequate venting must be ensured during hydrostatic testing to prevent collapse (sucking in) of the tank.
18. Pneumatic testing must be used with care to prevent a catastrophic failure caused by release of stored energy.

QUESTIONS FOR STUDY AND DISCUSSION

1. Can visual examination be used to find every type of cracking that a weld may exhibit?
2. What types of checks may be performed on metal before welding using visual examination?
3. Why is visual examination important during welding?
4. After welding, how should visual examination be applied to dimensional accuracy, weld appearance, and base metal integrity?
5. What is the difference between penetrant and developer in liquid penetrant examination?
6. Why must defects be open at the surface for liquid penetrant examination to be effective?
7. What is dwell time?
8. Why is arcing undesirable when prods are used for magnetic particle examination?
9. What is the purpose of couplant used in ultrasonic examination?
10. Why is radiographic examination commonly used to assess weld quality?
11. What types of artifacts may be present in radiographs that detract from accurate assessment of weld quality?

Metallography 33

Weld Evaluation and Testing

Metallography is the visual examination of the microscopic features of metal or weld surfaces that have been specially prepared by cutting, grinding, polishing, and etching. Metallography is used in failure analysis and as a quality control tool for production. In failure analysis, metallography is used to compare the actual weld quality with the specification and to reveal contributing causes of the failure. When used as a quality control tool, the tested specimen must be representative of the overall weld. The control specimen is then compared against set standards. Metallography may reveal cracking at an improperly made tack weld that progresses through subsequent weld passes. Metallography includes microscopic examination and macroscopic examination used to analyze discontinuities, weld passes and location, and metallurgical structure of the weld.

MICROSCOPIC EXAMINATION

Microscopic examination is concerned with the microscopic features of material surfaces. The purpose of microscopic examination is to look for clues as to how a metal was made and/or how it performed under load or working conditions. Microscopic examination is conducted at high magnification. Small specimens, representative of the component, are required. The sequence of steps in microscopic examination consists of cutting and rough grinding; mounting and fine grinding; rough and final polishing; and etching and examination.

Cutting and Rough Grinding

Cutting and rough grinding is performed to obtain a representative metallographic specimen from the joint. Specimen orientation must first be determined. Special techniques, such as preventing flattening when cutting thin-wall tubing, may be required to preserve the specimen from damage so that the essential features are not destroyed. For rough grinding, sequential cutting may be performed to obtain a suitably sized specimen. Rough grinding removes coarse material and features that result from the cutting process.

Microscopic examination consists of cutting and rough grinding; mounting and fine grinding; rough and final polishing; and etching and examination.

Specimen Orientation. The specimen orientation is selected to obtain a representative section of the joint. The most common specimen orientation is transverse. It can be used to investigate weld profile, weld width, weld penetration (depth of fusion), weld reinforcement, and weld area. If a transverse section is not cut exactly perpendicular to the plane of the weld, errors in weld penetration and weld area measurement may be introduced. Except in the most severe cases, errors introduced in sectioning are likely to be lower than sampling errors from variability along the

length of the weld. Transverse sections may be supplemented by longitudinal sections. If additional details are required, other specimen orientations may be necessary. See Figure 33-1.

Cutting. Cutting is the most common method of obtaining specimens from a component. Large specimens must be reduced in size using flame or plasma cutting. Subsequent cutting is accomplished using a power hacksaw, band saw, abrasive cutoff wheel, or diamond-tipped cutoff wheel. Power hacksaws or band saws are used on specimens that are too large or awkward to cut using an abrasive cutoff wheel. Abrasive cutoff wheels are used to obtain specimens that are close to the final size. Diamond-tipped cutoff wheels are used on small specimens where precision cuts are required. If a diamond-tipped cutoff wheel is used, the rough grinding steps are bypassed. See Figure 33-2.

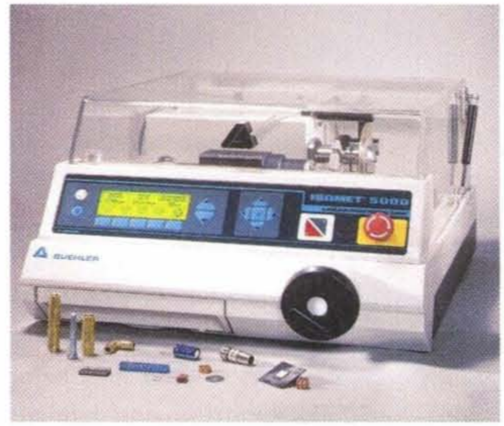


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Figure 33-2. *Diamond-tipped cutoff wheels are used on small specimens where precision cuts are required.*

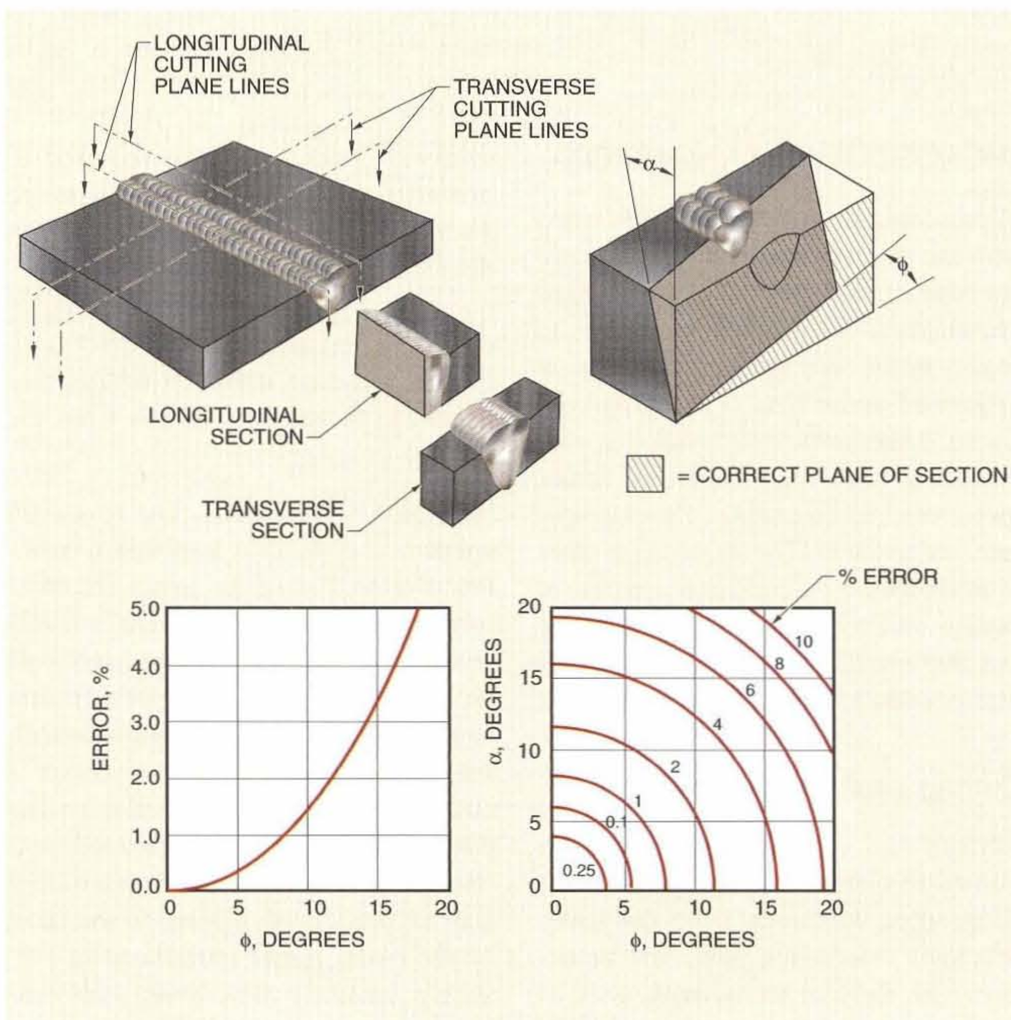

Figure 33-1. *Errors in measurement may be introduced when a transverse section is not taken exactly perpendicular to the plane of the weld.*

Overheating is microstructural damage or change caused by cutting operations. Flame or plasma cutting must be performed at a distance of $3/8''$ to $1/2''$ away from the area to be examined to prevent overheating, so that final cutting can be done with less damaging techniques. Cutoff wheels and saws use a coolant at the cutting surface to prevent overheating. Materials with hardness values greater than 35 HRC may require the use of an abrasive cutoff wheel or a diamond-tipped cutoff wheel for cutting operations.

Subsurface deformation is microstructural damage or change produced by cutting and that occurs below the surface of the specimen. Coarse cutting tools and heavy applications of force increase subsurface deformation that must be removed by grinding to prevent false interpretations of the microstructure.

Rough Grinding. Rough grinding prepares specimens for mounting by removing subsurface deformation, unnecessary roughness, and flash or scale caused by cutting operations. Specimens are ground flat on a wet abrasive belt sander using an 80-grit or 150-grit belt, or they are machined flat in a milling machine. When a diamond-tipped wheel is used to make the final cut, rough grinding is usually unnecessary.

Mounting and Fine Grinding

Specimen mounting is usually permanent, meaning that the specimen is permanently encased in resin. Some mounts have a temporary clamping device that holds the specimen flat and rigid during fine grinding. Before mounting, any burrs at the edges of the specimen caused by cutting or machining are carefully removed using a smooth file or coarse abrasive paper or cloth.

Mounting prevents rounding of the edges of specimens and allows handling during the polishing and etching stages. Selection of the correct mounting resin is based on a combination of factors. Fine grinding prepares the mount for the final stages of specimen preparation.

Hot Mounting. Hot mounting is usually performed in a mounting press that encapsulates the specimen with a thermosetting resin under pressure and at an elevated temperature. See Figure 33-3. The specimen is placed face down in a vertical, cylindrical mold in the mounting press. A predetermined amount of thermosetting resin is poured into the mold and the mold is closed. The temperature is raised and pressure is maintained while the resin cures, making the resin hard and strong. After the mold cools, the mount is removed from the mold.

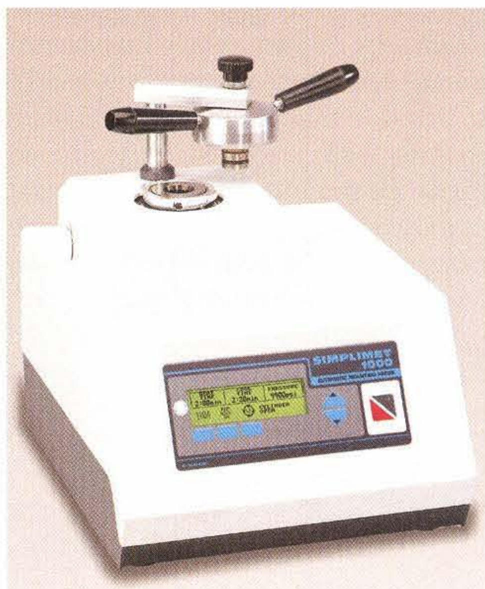

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Figure 33-3. *Mounting presses use compression and heat to encapsulate the specimen in a plastic mounting resin.*

A suitable mounting resin must cure at a temperature and pressure that does not alter the microstructure of the specimen. The mounting resin selected must resist chemical attack by the etchant, which is applied to the face of the mount to reveal microstructural features. The mounting resin must provide good adhesion to the edges of the specimen to prevent rounding of the edges and entry of lubricant or etchant during specimen preparation. Lubricant or etchant that enters the mount

during preparation will flow out after final preparation and cause staining of the specimen as it dries.

The mounting resin must fill pores and crevices on the exposed face of the specimen to prevent staining. It must also be electrically conductive if electrolytic polishing or etching is to be used. If side views of the specimen are required, the mounting resin must be transparent. See Figure 33-4.

Cold Mounting. Cold mounting is an alternative to hot mounting and is performed when the specimen is too large for the mounting press or when the heat involved might alter the microstructure. Cold mounting is performed in a vacuum to remove air bubbles from the mount. Room temperature and atmospheric pressure must be maintained when performing cold mounting using a thermoplastic resin.

Mounting is used to conveniently hold the specimen, to mount multiple specimens, and to store and label specimens. Mounting also protects the edges of the specimen and provides the proper specimen orientation.

MOUNTING RESINS

Plastic	Type	Molding Conditions			Heat-Distortion Temperature*‡	Transparency	Chemical Resistance
		Temperature*	Pressure†	Curing Time			
Phenolic molding powder	Thermosetting§	170	4000	5 min	140	Opaque	Not resistant to strong acids or alkalis
Acrylic (polymethyl methacrylate) molding powder	Thermoplastic	150	4000	none	65	Water white	Not resistant to strong acids
Epoxy casting resin	Thermosetting‖	20-40	—	24 hr	60#	Clear but light brown in color	Fair resistance to most alkalis and acids; poor resistance to nitric and glacial acetic acids
Diallyl molding compound	Thermosetting**	160	2500	6 min	150	Opaque	Not resistant to strong acids and alkalis
Formvar® (polyvinyl formal) molding compound	Thermoplastic	220	4000	none	75	Clear but light brown in color	Not resistant to strong acids
Polyvinyl chloride molding compound	Thermoplastic††	160‡‡	3000	none	60	Opaque	Highly resistant to most acids and alkalis

* °C
† in psi
‡ determined by method in *ASTM D 648-56*, at a fiber stress of 264 lb/in.^{2}
§ wood-filled grade, preferably with low filler content
‖ liquid epoxy resin with an aliphatic amine hardener
depends on curing schedule (can be as high as 110°C with heat curing)
** diallyl phthalate polymer with a mineral filler
†† stabilized ridged PVC
‡‡ must not exceed 200°C

Figure 33-4. *Mounting resins must satisfy a variety of conditions to be acceptable.*

Fine Grinding. Fine grinding is the last stage before polishing of the mount. It consists of abrading the mount on a series of successively finer abrasive papers. Before fine grinding, any resin on the face of the specimen or any remaining burrs on the edges are removed by a 120-grit abrasive paper or cloth. During fine grinding, a series of water-lubricated papers, ranging from 240-grit to 600-grit, are used. The mount is lightly washed between abrasive papers or belts to prevent carryover of coarser abrasive material.

Two commonly used types of fine grinding are four-stage belt sanding and four-stage wheel grinding. Four-stage belt sanding uses an assembly of four strips of abrasive paper of increasing fineness. The mounted specimen is moved up and down on each grade of paper without rocking the mount. The mounted specimen is abraded backward and forward without rotation until all sanding marks from the previous coarser abrasive paper have been eliminated. See Figure 33-5.

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Figure 33-5. *Grinding in four-stage belt grinding starts with 240-grit and finishes with 600-grit paper.*

Four-stage wheel grinding is performed on a grinding wheel by changing the abrasive material at each stage to eliminate successively finer scratches. Ample water lubrication must be used to prevent overheating.

With either four-stage belt sanding or four-stage wheel grinding, the amount of time spent on each abrasive material is increased as finer grades of material are used. Excessive sanding with any grade of abrasive paper must be avoided as it may cause subsurface deformation that cannot be eliminated by subsequent grades of abrasive paper and that leads to artifacts. The mount is thoroughly washed and dried after fine grinding is completed.

The direction of grinding is changed 90° with each change of abrasive paper, so that complete removal of the previous grinding marks is achieved. See Figure 33-6.

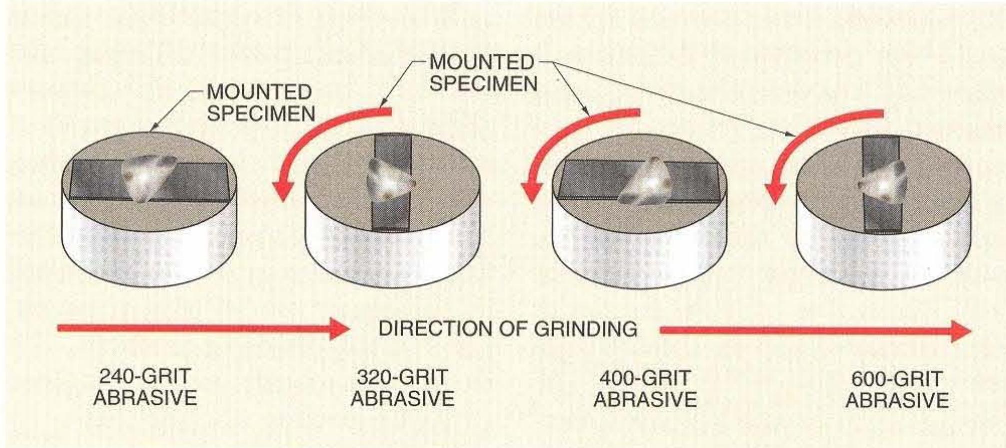
Rough and Final Polishing

Rough and final polishing procedures are used to develop a scratch-free mirror finish on the specimen. The specimen is polished using manual, mechanical, electrolytic, or chemical techniques. The surface must be free from pits (small, sharp depressions) and subsurface deformation effects that lead to artifacts when the specimen is etched. Pits are caused by the polishing operation that removes tiny nonmetallic particles such as carbides from the metal surface.

Wall Colmonoy

Microscopic examination procedures are typically performed in a lab by trained technicians.

Figure 33-6. *The mount is rotated 90° and thoroughly washed between successive papers to prevent carryover of abrasive materials.*



Rough Polishing. *Rough polishing* is a polishing process that is performed on a series of rotating wheels covered with a low-nap cloth (cloth containing a small amount of fiber). Successively finer grades of diamond rouge (polishing powder) are applied to each wheel, usually starting at 45 μ size. The grades usually decrease from 30 μ to 6 μ to 1 μ. A small amount of lubricant is applied to the cloth to prevent overheating of the mount. The mount is washed with liquid soap and water, alcohol, or acetone between each polishing to prevent carryover of diamond rouge.

Final Polishing. Final polishing is similar to rough polishing, but during final polishing very light hand pressure is applied to the mount. After washing and drying in a current of warm air, the mount is examined under a metallurgical microscope for scratches. If the mount is scratch-free, it is ready for etching and examination under a metallurgical microscope.

Final polishing is done by rubbing the mount against a medium-nap cloth that has a .3 μ to .05 μ alumina slurry applied to it. If the specimen surface is to be subjected to microanalysis, alumina should not be used. The presence of alumina during microanalysis may lead to misinterpretation of the results of the microanalysis. *Microanalysis* is chemical analysis of extremely small regions of the specimen surface using tools such as energy-dispersive X-ray analysis or electron probe microanalysis.

Automatic Polishing. Automatic polishing is a process that establishes a complex motion for the mount relative to the rotation of the polishing wheel. The rough and final polishing steps are performed in an automatic polishing machine. The machine setting is determined from operator experience. Automatic polishing is used for large batches of repetitive work, for radioactive specimens, and for polishing techniques that add corrosives to the wheel. See Figure 33-7.

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Figure 33-7. *Automatic polishing in an automatic polishing machine establishes a complex motion for the mount relative to the rotation of the polishing wheel.*

Electrolytic and Chemical Polishing. Electrolytic polishing and chemical polishing are methods of preparation that bypass the rough and final polishing

stages. *Electrolytic polishing* is a polishing process in which the mount is the anode (connected to the positive terminal) in an electrolytic solution and current is passed from a metal cathode (connected to the negative terminal). The current is passed through the electrolytic solution between the anode and the cathode. The current removes the rough peaks on the specimen surface. If the grain structure is homogeneous and single-phase (consisting of one crystallographic component), a mirror-polished surface is obtained. See Figure 33-8.

Chemical polishing is a polishing process that uses chemical reactions to remove the rough peaks on the specimen surface. The mount is immersed in a specific chemical that dissolves the high peaks on the specimen to produce a mirror-polished finish. Chemical polishing is similar to electrolytic polishing in that it removes the rough peaks on the specimen surface and produces a mirror-polished surface.

Etching and Examination

Etching, followed by examination of the mounted specimen with a metallurgical microscope, is the last stage of metallographic preparation before microstructural examination. Etching is necessary to reveal the microstructural detail of the polished specimen, assists in determining the features of the weld, and makes visible the boundary between the weld metal and the base metal. The etched specimen is examined under reflected light in a metallurgical microscope.

Etching a Specimen. Etching is the controlled selective attack on a metal surface to reveal the microstructural detail of a polished specimen. Before etching, the specimen is examined with a metallurgical microscope in the as-polished condition. Besides revealing minor scratches that must be removed, etching also makes microstructural features such as inclusions and porosity easy to observe.

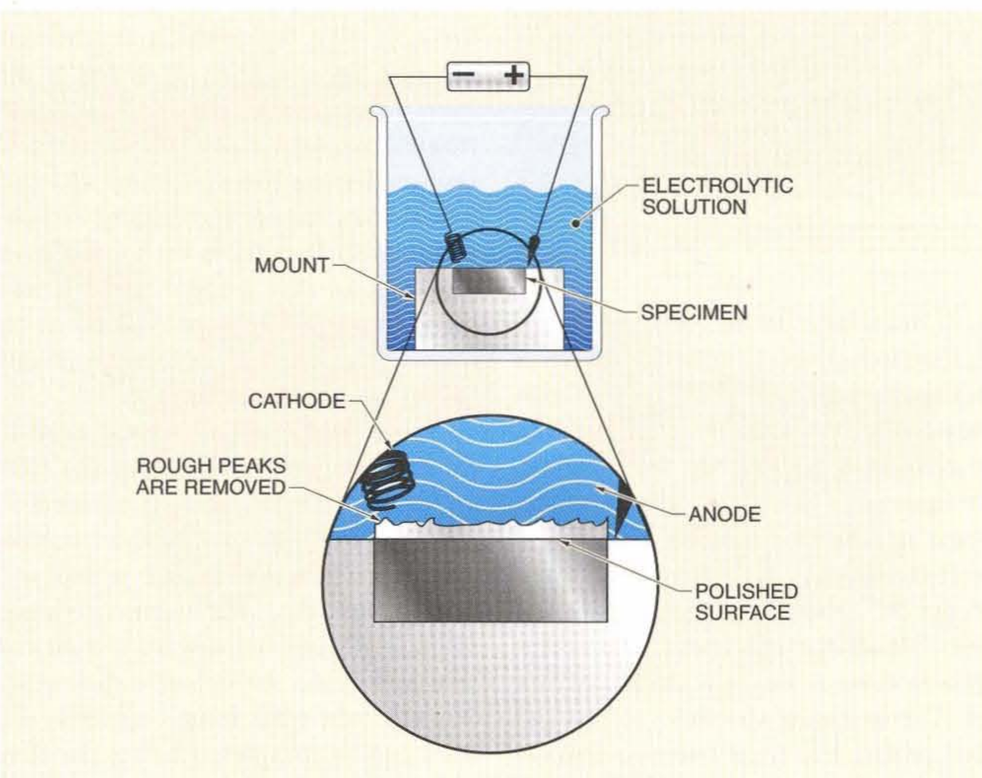


Figure 33-8. *Electrolytic polishing removes rough peaks on a specimen with the flow of current between an anode and a cathode.*

The specimen is then thoroughly degreased, dried, and prepared for etching. Etching is the last stage before examination. Etchants selectively dissolve specific microstructural components, giving the as-polished surface a relief appearance. Etchants are selected to distinguish various microstructural components to provide the best view of the microstructural features.

Etching often requires the use of strong acids, and all safety precautions must be observed. Always add acid to water when diluting, not vice versa.

Etching is usually performed by immersion. The specimen is immersed with the polished face upward in a small dish of etching solution, which is gently swirled. The specimen is removed when a bloom appears. A *bloom* is a slight haze that appears on the surface of the specimen and is evidence of the first appearance of the microstructure. See Figure 33-9.

Etched Specimen
Figure 33-9

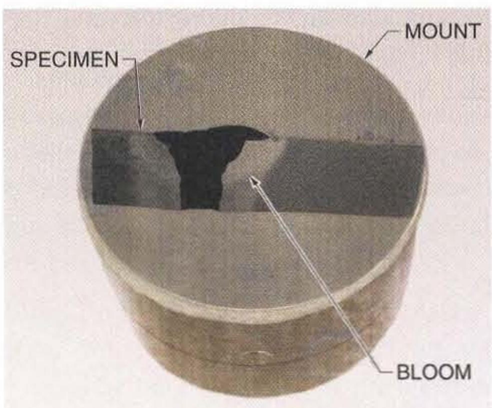


Figure 33-9. *For optimum viewing of the microstructure, the mount is etched until a bloom appears on the surface.*

⚠ WARNING

Always add acid to water when diluting. Nitric acid causes stains and severe burns. Wash affected areas with water immediately if the nitric acid mixture touches the skin.

If necessary, further etching may be performed after examination under a microscope to strengthen any details. However, over-etching may cause loss of contrast. After etching, the specimen is thoroughly rinsed in running water. Then acetone or alcohol is sprayed over the surface. The excess is allowed to run off against a cloth that is held at one side of the specimen. The specimen is then dried in a stream of hot air. The specimen should be etched and fine polished at least twice to remove flowed metal from the surface.

Specimen Examination. Metallurgical microscope examination uses light reflected from the specimen surface to examine microstructural details. The surface of the specimen must be widely scanned to gain a representative view of the microstructure. Details are revealed because etching attacks the grains of metal at different rates, which results in various shading effects. The proper amount of etching is required for optimum viewing of the microstructure. Improper amounts of etching lead to overetching or underetching, resulting in false effects. See Figure 33-10.

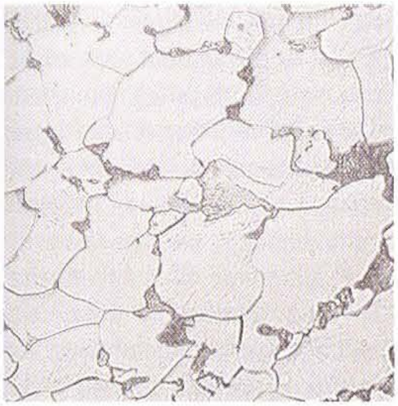
The etched specimen is placed in a metallurgical microscope and examined at low-power magnification of 25x or 50x to obtain an overall impression of the microstructure. It is then examined at increasing magnifications of 100x to 1000x to reveal fine detail. Higher magnifications up to 2500x cannot be achieved within the air space available between the lens and the specimen.

Higher magnifications require the use of water or oil immersion. A small amount of water or oil is daubed on the objective lens, which is lowered towards the specimen. If water or oil immersion is to be followed by lower magnification work, the water or oil is removed from the specimen and the mount may require repolishing and re-etching. Surface films on some alloys may require that specimens are repolished and re-etched several times to remove the affected surface layer and reveal their true structure.

When focusing the metallurgical microscope, contact between the lens and the specimen must be avoided to prevent surface damage to the mounted specimen.

When focusing the metallurgical microscope, contact between the lens and the specimen must be avoided to prevent surface damage to the mounted specimen. The microscope is focused in two steps. First, the microscope stage is gradually moved toward the objective lens using the coarse adjustment. Second, when the image appears, the focusing is completed using the fine adjustment.

Specimen Etching
Figure 33-10



PROPER ETCHING | OVERETCHING | UNDERETCHING

Figure 33-10. *Properly etched specimens reveal true microstructural features when viewed by a metallurgical microscope.*

Metallurgical microscopes vary from small benchtop units to larger units that have their own framework. Some are equipped with a video camera and monitor that are used to view microstructures. See Figure 33-11. A *metallograph* is a metallurgical microscope equipped to photograph microstructures and produce photomicrographs. Photomicrographs are photographs of microstructures.

Interpretation problems such as artifacts and surface films may hinder metallurgical microscopic examination. An artifact does not correspond to the true microstructure and occurs during metallographic specimen preparation. Artifacts result from incomplete removal of a thin surface layer that has been affected by the specimen preparation process. For example, overheating

Metallurgical Microscopes
Figure 33-11

Figure 33-11. *The benchtop metallurgical microscope is commonly used for speciman examination.*

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during cutting may give the false impression that the specimen was heat-treated.

Specimens may need to be repolished and re-etched if interpretation problems occur during preparation.

Illumination. Different types of illumination enhance the appearance of the microstructural characteristics of the specimens. These include brightfield illumination, darkfield illumination, polarized illumination, and Nomarski illumination. See Figure 33-12.

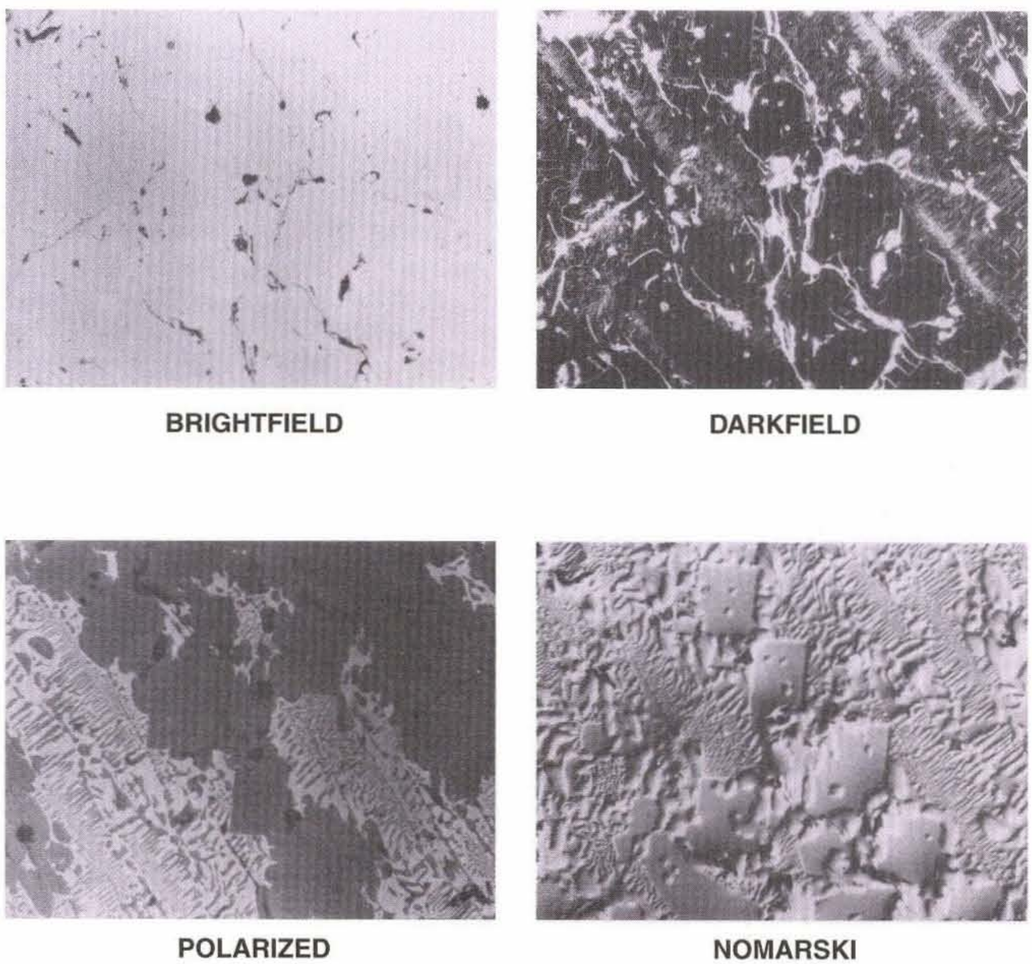
Brightfield illumination is an illumination process in which the surface features perpendicular to the optical axis of the microscope appear the brightest. Brightfield illumination is the most common form of illumination used with a metallurgical microscope. The surface of the specimen is placed perpendicular to the optical axis of the microscope and a white light is used.

Darkfield illumination is an illumination process that illuminates the specimen at sufficient obliqueness (a narrow angle to the surface) so that the contrast is completely reversed from that obtained with brightfield illumination. Those areas that are bright in brightfield will be dark in darkfield and vice versa. Darkfield illumination is useful for highlighting microstructural features (inclusions, grain boundaries, and cracks) that are dark and difficult to distinguish under brightfield illumination.

Figure 33-12. *The four illumination forms for micrographs are brightfield, darkfield, polarized, and Nomarski illumination.*

When examining metallographic samples under a metallurgical microscope, illumination techniques such as brightfield, darkfield, polarized, and Nomarski may be used to reveal microstructural features.

Illuminations for Micrographs
Figure 33-12



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Polarized illumination is an illumination process that reveals microstructural features in metals that are optically anisotropic. Optically anisotropic describes a microstructural feature in which the microstructure has optical properties that vary with changes in the viewing direction. The light is polarized by placing a polarizer in front of the condenser lens of the microscope and placing an analyzer behind the eyepiece. A *polarizer* is a device into which normal light passes and from which polarized light emerges.

Nomarski illumination is an illumination process that illuminates the specimen using polarized light that is separated into two beams by a biprism. A *biprism* is two uniaxial, double-refracting crystals. The beams are reflected back through the biprism off of the specimen surface. The biprism combines the beams into one beam, which is run though an analyzer and viewed through an eyepiece. Images produced are three-dimensional and vary in color. This variation in dimension and color is used to identify metals and their various phases.

MACROSCOPIC EXAMINATION

Macroscopic examination is used to reveal the general structure of large areas of a specimen because they might not be revealed under the higher magnifications used in microscopic examination. Macroscopic examination is performed with the naked eye or at magnifications up to 10x using a binocular microscope. Larger specimens are used for macroscopic examination than are used for microscopic examination. A specimen for macroscopic examination is usually an entire section through a component. These specimens are used to reveal gross elements of fabrication quality, such as size of weld.

Macroscopic examination consists of specimen preparation; rough and fine grinding; and macroetching and examination. Photography may be used to document macroscopic examination.

Specimen Preparation

Specimen preparation for macroscopic examination consists of removing a slice, by flame cutting or sawing, in the plane to be examined. Fabrication codes and standards may indicate where cuts must be taken to produce acceptable specimens for macroscopic examination.

Rough and Fine Grinding

Rough and fine grinding procedures are similar to those used in microscopic examination. Fine grinding is performed to a final finish with a 240-grit abrasive. Unlike microscopic examination, the specimen is not mounted.

Applications of macroetching are to study the weld structure; to measure joint penetration; to detect lack of fusion; and to determine whether slag, flux, porosity, or cracks are present in the weld and the heat-affected zone.

Macroetching and Examination

Macroetching differs from etching used for microstructural examination and requires the use of macroetchants. *Macroetchants* are deep etchants that are intended to develop gross features such as weld solidification structures. Macroetchants are designed to attack metal more deeply and more quickly than metallographic etchants. See Figure 33-13.

Macroscopic examination may be used to examine specimens with large test surface areas.

Different etchants, such as hydrochloric acid, ammonium hydroxide-peroxide, or nitric acid, are used to reveal specific types of microstructural details. After the etching process, the specimen is ready for examination in a metallurgical microscope. See Appendix.

Macroscopic examination consists of specimen preparation; rough and fine grinding; and macroetching and examination.

A hydrochloric acid solution should contain equal parts by volume of concentrated hydrochloric (muriatic) acid and water. Immerse the weld in the

boiling reagent. Hydrochloric acid will etch unpolished surfaces. It usually enlarges gas pockets and dissolves slag inclusions, enlarging the resulting cavities.

An ammonium hydroxide-peroxide solution should contain one part ammonium persulfate (solid) and nine parts water by weight. Vigorously rub the surface of the weld with cotton saturated with the ammonium persulfate reagent at room temperature.

Nitric acid etches rapidly and should only be used on polished surfaces. It will show the refined zone as well as the metal zone. Mix one part concentrated nitric acid to three parts water by volume. Either apply the reagent to the surface of the weld with a glass stirring rod at room temperature or immerse the weld in boiling reagent, provided the room is well ventilated. After etching, wash the weld immediately in clear, hot water. Remove excess water. Dip the etched surface in ethyl alcohol; then remove and dry it in a steady blast of warm air.

An iodine and potassium iodide solution is obtained by mixing one part powdered iodine (solid) to 12 parts of a solution of potassium iodide by weight. The potassium iodide solution should consist of one part potassium iodide to five parts water by weight. Brush the surface of the weld with this reagent at room temperature.

Figure 33-13. *Macroetchants are deep etchants intended to develop gross features such as weld solidification structures.*

MACROETCHANTS		
Etching Solution	**Surface Preparation***	**Comments**
Carbon and Low-Alloy Steels 10 g $(NH_3)_2S_2O_8$ (ammonium persulfate) + 100 mL H_2O	B	Swab; macroetch brings out fusion line, heat-affected zone, reheated zones, columnar zones
15 mL HNO_3 + 85 mL H_2O + 5 mL methanol or ethanol	A, B	Swab; macroetch brings out fusion line, heat-affected zone, reheated zones, columnar zones; scrub gently under running water to remove any black residue
8 mL HNO_3 + 2 g picric acid + 10 g $(NH_3)_2S_2O_8$ + 10 g citric acid + 10 drops (.5 mL) benzalkonium chloride + 1500 mL H_2O	B	Immerse; highlights partially transformed regions in reheat and heat-affected zones (Ref 13)
Aluminum Alloys Tucker's reagent, 45 mL HCl + 15 mL HNO_3 + 15 mL HF (48%) + 25 mL H_2O	A, B	Immerse or swab; use freshly mixed general macroetch; all alloys
Poulton's reagent, 60 mL HCl + 30 mL HNO_3 + 5 mL HF (48%) + 5 mL H_2O	A, B	Immerse or swab; general macroetch, all alloys
Copper and Copper Alloys 50 mL HNO_3 + .5 g $AgNO_3$ (silver nitrate) + 50 mL H_2O	A, B	Immerse; general macroetch, all alloys
Titanium Alloys Kroll's reagent, 10–30 mL HNO_3 + 5–15 mL HF + 50 mL H_2O	B	Immerse; general macro- and microetch; increase HNO_3 and reduce HF to bring out the fine structures in weldments

* surface preparation: A, finish grind; B, polish

Macroetching. Macroetching is usually performed by gently daubing the sample with the macroetchant or by immersing smaller specimens in the macroetchant and gently swirling. Higher temperatures accelerate the etching rate. Prolonged etching is avoided because it leads to darkening of the specimen, which obscures detail. When the structural features are developed, the specimen is immediately rinsed in warm running water. During rinsing, the surface should be scrubbed with a soft bristle brush to remove deposits formed during macroetching. Deposits may contain residual macroetchant and may lead to localized overetching if the macroetchant is not thoroughly removed. The washed specimen is dried by squirting it with alcohol or acetone, which is allowed to drain into a cloth that is held at one side of the mount, and then drying the specimen in a current of warm air.

The surface must be preserved as quickly as possible after drying, once it has been determined that the amount of macroetching is adequate. Preservation consists of coating the surface with a clear lacquer. If the surface is not preserved it will oxidize and darken with time and lose surface features.

Examination. Examination of macroetched samples may be performed with the naked eye or under a binocular microscope. A *binocular microscope* is a light microscope that provides a low-magnification, three-dimensional view of the surface. A binocular microscope is limited to a magnification of 30x to 50x for most work. The magnification of a binocular microscope is limited by the required depth of field. *Depth of field* is the total depth of the image that can be maintained in focus within a lens. The rougher the surfaces of a weld or its macroetched face, the lower the useful magnification and the greater the depth of field required. Macroscopic examination is described in ASTM E 381, *Macroetch Testing, Inspection, and Rating of Steel Products, Comprising Bars, Billets, Blooms, and Forgings.*

Photomacrography is the documentation of macroetched samples using photography. Photomacrography is performed using an overhead digital camera. A ruler is placed alongside the specimen to indicate scale. The roughened surface attained through macroetching must be in focus to achieve adequate resolution. Resolution is controlled by the depth of field of the lens. Depth of field is controlled by three factors: the focal length of the lens, the aperture (area) of the lens, and the distance between the surface and the lens. Depth of field varies as the inverse square of the focal length. For example, if the focal length is reduced by one half, the depth of field increases by a factor of four. Depth of field doubles as the aperture setting (f-stop number of the lens) doubles. The f-stop indicates the aperture size of the lens. Depth of field is proportional to the square of the distance of the surface from the lens. For example, if the aperture size of the lens is increased by a factor of three, the depth of field increases by a factor of nine.

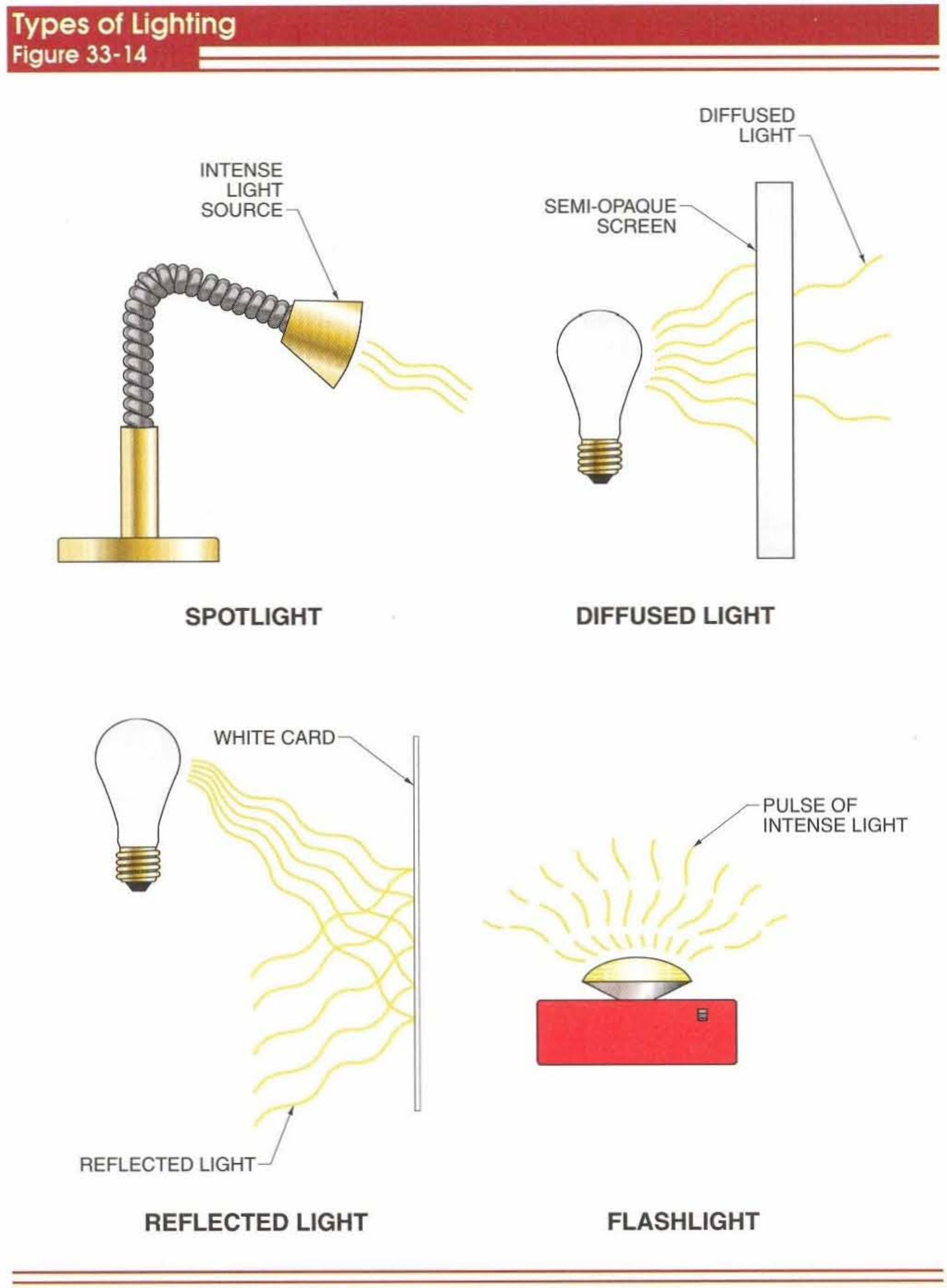
Lighting

Lighting has the greatest overall effect on the appearance of a surface. Proper use of lighting sources and lighting methods permits key features and morphology of the specimen to be revealed. The four types of lighting sources are spotlight, diffused light, reflected light, and flashlight. See Figure 33-14.

A *spotlight* is an intense lighting source that uses a single bulb in a reflector. *Diffused light* is a lighting source that uses a semi-opaque screen (such as ground glass) to diffuse the light source, reduce glare, and soften harsh details. *Reflected light* is a lighting source that bounces light off a white card, wall, or ceiling. The effect produced is similar to the effect produced by diffused light. A *flashlight* is a lighting source that provides a pulse of very intense light. A flashlight is the best light source (next to direct sunlight) for color photography of uneven surfaces.

Magnification, resolution, and lighting are the three most important methods of photography used for documenting macroscopic examination features.

Figure 33-14. *The four types of lighting sources are spotlight, diffused light, reflected light, and flashlight.*



The four types of lighting methods are main lighting, fill lighting, backlighting, and buildup lighting. These lighting methods use combinations of the four types of light sources to achieve the desired lighting effect.

Main lighting is a primary lighting method that uses a light source at a vertical angle of 40° to 60° to the subject. *Fill lighting* is a lighting method that uses a small region of a brighter light to increase detail on a dark area of a subject. The light source for fill lighting may be spotlight, diffused light, or reflected light. *Backlighting* is a lighting method that uses a diffused light source to eliminate or soften shadow detail. A light box (lighted ground-glass screen) behind the specimen is the most common diffused light source for backlighting. *Buildup lighting* is a lighting method that combines (adding or deleting) light sources to achieve the desired lighting effect. See Figure 33-15.

Lighting Methods for Macroscopic Examination
Figure 33-15

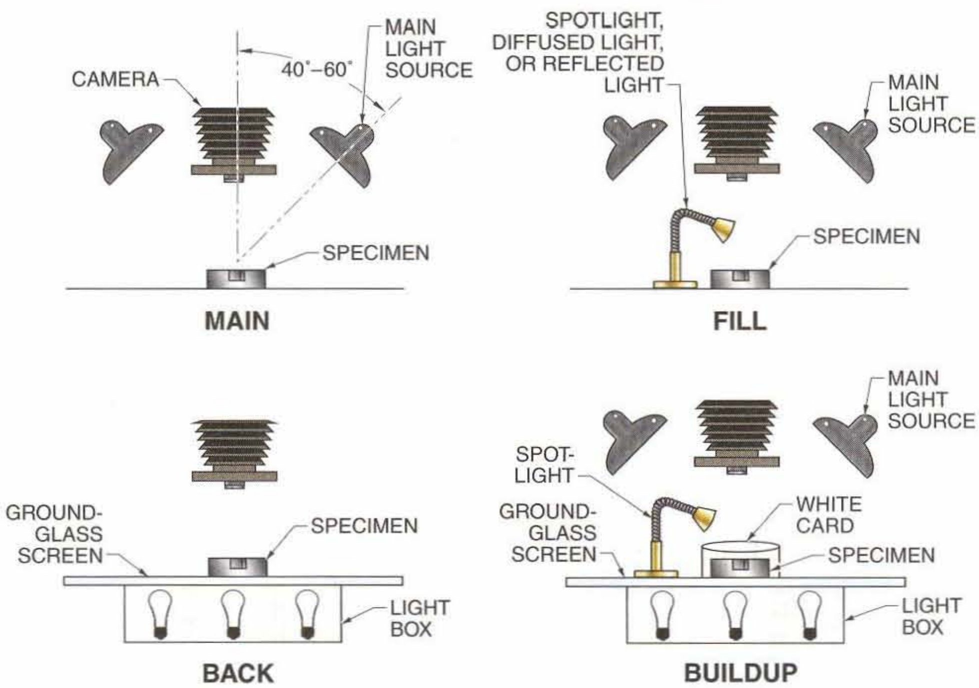


Figure 33-15. *Proper selection and use of lighting methods permits key features on a fracture surface to be revealed.*

POINTS TO REMEMBER

1. The stages of metallography include cutting and rough grinding, mounting and fine grinding, rough and final polishing, and etching and examination.
2. Etching often requires the use of strong acids, and all safety precautions must be observed. Always add acid to water when diluting, not vice versa.
3. When focusing the metallurgical microscope, contact between the lens and the specimen must be avoided to prevent surface damage to the mounted specimen.
4. When examining metallographic samples under a metallurgical microscope, illumination techniques such as brightfield, darkfield, polarized, and Nomarski may be used to reveal microstructural features.
5. Macroscopic examination may be used to examine specimens with large test surface areas.
6. Macroscopic examination consists of specimen preparation; rough and fine grinding; and macroetching and examination.
7. Magnification, resolution, and lighting are the three most important methods of photography used for documenting macroscopic examination features.

QUESTIONS FOR STUDY AND DISCUSSION

1. What types of weld attributes may be studied using metallography?
2. Why must overheating be avoided when cutting specimens for metallographic examination?
3. What is the minimum distance the heat source must be kept from the area of interest when burning is used to remove specimens?
4. What is the purpose of rough grinding for metallographic examination?
5. What is macroscopic examination?
6. Why are successively finer stages of grinding and polishing used to prepare a specimen for metallographic examination?
7. Why must a polished specimen be etched before examination under a metallurgical microscope?
8. What is the difference between microetchants and macroetchants?
9. What type of light does a metallurgical microscope use?
10. How does the magnification range of a metallurgical microscope compare with that of a binocular microscope?
11. What is the meaning of depth of field when used in the examination of macroscopic specimens?

Weld Discontinuities 34

Weld Evaluation and Testing

Weld discontinuities are interruptions in the structure of a weld and are not necessarily weld defects. Weld discontinuities are caused by poor weld design, improper welding procedures, and improper welder techniques. Weld discontinuities are grouped according to their nature.

Weld defects are weld discontinuities that fail to meet the requirements of the codes or standards by which the weld is made. A weld defect requires that the weld be rejected, or repaired and reexamined. Weld defects are not permitted by controlling codes or standards because they can lead to premature failure. Various nondestructive examination (NDE) techniques are used to detect weld defects and discontinuities and measure their size and orientation.

WELD DISCONTINUITIES

A *weld discontinuity* is an interruption in the typical structure of a weld. Weld discontinuities can occur in the weld metal, the heat-affected zone (HAZ), or the base metal. Their location varies depending upon the type of weld. A weld discontinuity is not always considered a defect. The transition point between a discontinuity and a defect depends upon the fabrication standard or code that controls the welded joint design and quality.

Discontinuities are detected by nondestructive examination (NDE). The most common NDE techniques used are visual examination (VT), magnetic particle examination (MT), liquid penetrant examination (PT), radiographic examination (RT), and ultrasonic examination (UT). The most applicable NDE technique or techniques are selected to locate and measure the size and orientation of the discontinuity. The discontinuity size and orientation are then compared with what is allowable in the applicable fabrication standard or code to decide whether the discontinuity is a defect and whether the weld should be accepted or rejected.

A discontinuity is an interruption in the structure of a weld. Discontinuities are not always defects.

Weld Defects

Weld defects result from weld discontinuities that by their nature or their accumulated effect are unable to meet the minimum acceptable requirements of the applicable fabrication standard or code. An unacceptable discontinuity under certain service conditions may be acceptable in a less demanding service or in another metal. Refer to the requirements of the fabrication code or standard that governs the quality of the welded joint under consideration. See Figure 34-1. A weld defect requires rejection of the part.

A discontinuity is a crack, flaw, or imperfection in a base material or weld metal. Discontinuities are classified by their nature (how they alter stresses in the weld) and by their shape, which encompasses their orientation with respect to the working stress and their location with respect to the weld.

Discontinuities are classified as defects when they exceed the minimum requirements permitted by the controlling code or standard.

WELD DEFECT EVALUATION GUIDE			
Types of Defect	**Pipelines (per API Std. 1104)**	**Storage Tanks (per API Std. 650)**	**Power Boilers (per ASME Section 1)**
Cracks	None allowed (except shallow crater cracks in the cover pass with maximum length of 5/32″)	None Allowed	None Allowed
Incomplete Penetration at root pass	• Maximum of 1″ in length in 12″ of weld, or 8% of weld length if less than 12″ • Maximum individual length of 1″	None Allowed	None Allowed
Incomplete Penetration due to high-low fit-up	• Maximum individual length of 2″ • Maximum accumulated length of 3″ in 12″ of continuous weld	None Allowed	None Allowed
Lack of Fusion at root pass	• Maximum of 1″ in length in 12″ of weld, or 8% of weld length if less than 12″ • Maximum individual length of 1″	None Allowed	None Allowed
Lack of Fusion at groove face or between beads, "cold lap"	• Maximum individual length of 2″ • Maximum accumulated length of 2″ in 12″ of continuous weld	None Allowed	None Allowed
Melt-through	**Pipe Diameter** / **Maximum Defect** / **Maximum Total** less than 2¾″ OD / ¼″ / 1″ greater than or equal to 2¾″ OD / ¼″ / ½″ in 2″	Not Covered	Not Covered
Internal Concavity	If density of radiographic image of internal concavity is less than base metal, any length is allowable. If more dense, then see burn-through above	Shall not reduce weld thickness to less than thinner material. Contour of concavity shall be smooth	Not Covered
Undercut at Root pass or cover pass	• Maximum depth 1/32″ or 12½% wall thickness, whichever is smaller. • Maximum 2″ length or ⅙ wall thickness, whichever is less, for depth of 1/64″ to 1/32″ or 6% to 12½% of wall thickness, whichever is less	• For horizontal butt joints: maximum depth 1/32″ • For vertical butt joints: maximum depth 1/64″	1/32″ or 10% t†, whichever is less
Slag Inclusions elongated, except as noted	• Maximum length is 2″ and width 1/16″ • Maximum total length 2″ in 12″ of weld. Parallel slag lines are considered separate if width of either exceeds 1/32″. Isolated Slag Inclusions: • Maximum width ⅛″ and ½″ length in 12″ of weld. • No more than 4 isolated inclusions of ⅛″ maximum width.	**Material Thickness** / **Maximum Slag Length** less than or equal to ¾″ / ¼″ ¾″ to 2¼″ / ⅓t† greater than 2¼″ / ¾″ Maximum length of t† in 12t† length	**Material Thickness** / **Maximum Slag Length** less than or equal to ¾″ / ¼″ ¾″ to 2¼″ / ⅓t† greater than 2¼″ / ¾″ Maximum total length of t† in 12t† length
Porosity	Spherical: Maximum dimension ⅛″ or 25% of wall	• For aligned rounded indications, the	• For aligned rounded indications, the

* 100% X-Ray, Random X-Ray, and Spot X-Ray are quality level designations used by the ASME pressure vessel and ANSI piping codes and are also used when other NDE methods of evaluation are used
† t = weld thickness
‡ T = thinner material thickness
§ w = weld width
‖ see UHT-20 for special heat-treated ferritic steels
\# joint category A
** joint categories B, C, and D

Figure 34-1. *Fabrication standards and codes govern the acceptable quality of a welded joint, and are the determining factor in the acceptance or rejection of a weld. See Appendix.*

Weld stresses may be concentrated or enhanced by the presence of discontinuities, leading to failure under load.

Weld Stresses

Weld stresses may be increased or concentrated in a specific area by defects. Weld stresses are magnified when discontinuities reduce the cross-sectional area of the weld that is available to support the load. The average stress on a weld is in direct proportion to the reduction of the load-bearing cross-sectional area caused by the discontinuity. The lower the load-bearing cross-sectional area, the higher the stress. If the load-bearing cross-sectional area of a weld is reduced sufficiently, structural failure may occur under load. See Figure 34-2.

Concentrated weld stresses occur at discontinuities that create abrupt changes of geometry, resulting in a notch effect. A *notch effect* is a stress-concentrating condition caused by an abrupt change in section thickness or in continuity of the structure. The sharper the change of geometry in the

notch effect, the greater the stress concentration. Tensile stresses perpendicular to the notch and shear stresses parallel to the notch are concentrated at the tip of the notch. Extremely high stress concentrations can develop at extremely sharp notches created by planar-type discontinuities such as cracks, laminations, or incomplete fusion. Such discontinuities may lead to catastrophic fracture in service. See Figure 34-3.

Weld Stresses
Figure 34-2

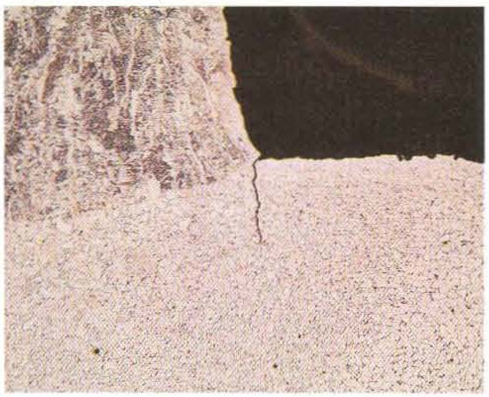


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Figure 34-2. *If the load-bearing area of a weld is sufficiently reduced, structural failure may occur when the part is placed under load.*

Cracks are the most serious type of imperfection that can occur in welds. Cracks should always be removed because they reduce the strength of the weld.

Discontinuities that concentrate stresses are usually more detrimental than discontinuities that amplify stress. Weld discontinuity types are cracks, cavities, inclusions, incomplete fusion and incomplete penetration, incorrect shape, and miscellaneous discontinuities.

CRACKS

A *crack* is a fracture-type discontinuity characterized by a sharp tip and a high ratio of length to width, and width to opening displacement. Cracks are the most serious discontinuities in weldments and are not permitted in fabrication standards and codes. Cracks are not permitted because they create significant stress concentrations at their tips. See Figure 34-4. When cracking is observed during welding, it must be removed before welding continues. Weld metal that is deposited over a crack can result in extension of the crack into newly deposited weld metal.

Cracks are fracture-type discontinuities and are not permitted in fabrication standards and codes.

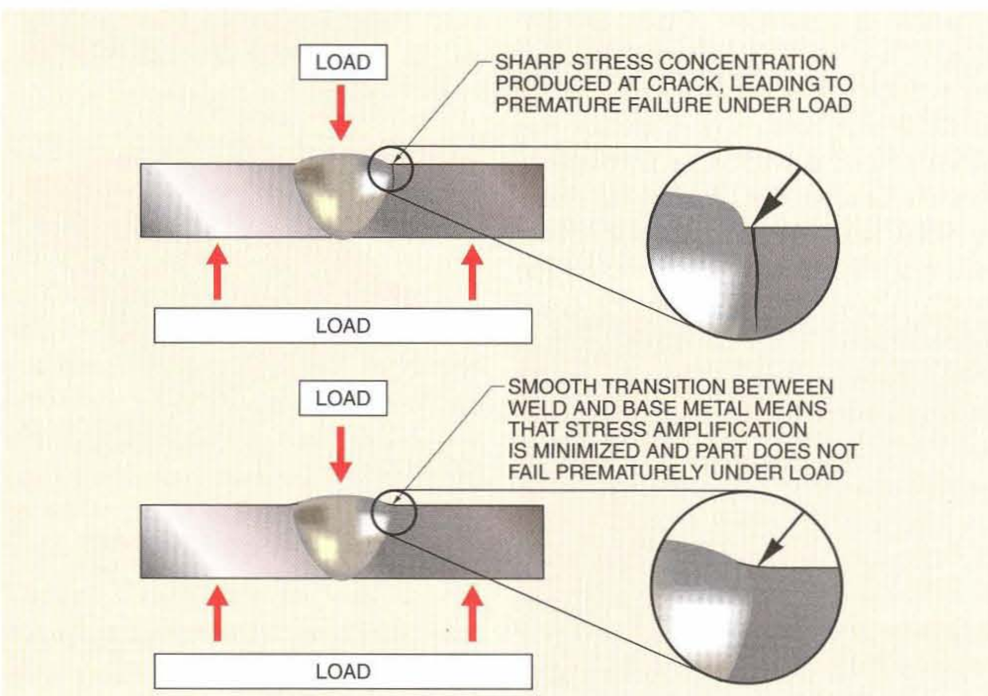


Figure 34-3. *Discontinuities that concentrate stresses are more detrimental than discontinuities that amplify stresses, and may lead to catastrophic fracture and failure in service.*

Figure 34-4. *Cracks are not permitted in metal because they create significant stress concentrations at their tips. Cracks must be removed before welding continues.*

CRACK PREVENTION	
Problem	**Preventive Measure**
Weld Metal	
Highly rigid joint	Preheat
	Relieve residual stresses mechanically
	Minimize shrinkage stresses using back-step or block welding sequence
Excessive dilution	Change welding current and travel speed
	Weld with covered electrode, DCEN; butter the joint faces prior to welding
Defective electrodes	Change to new electrode; properly store and maintain electrodes to prevent moisture and damage
Poor fit-up	Reduce root opening; build up edges with weld metal
Small weld bead	Increase electrode size; raise welding current; reduce travel speed
High-sulfur base metal	Use low-sulfur filler metal
Angular distortion	Change to balanced welding on both sides of joint
Crater cracking	Fill crater before extinguishing the arc; use a welding current decay device when terminating the weld bead
Heat-Affected Zone	
Hydrogen in welding atmosphere	Use low-hydrogen welding process; preheat and hold for 2 hr after welding or postheat immediately
Hot cracking	Use low heat input; deposit thin layers; change base metal
Low ductility	Use preheat; anneal base metal
High residual stresses	Redesign the weldment; change welding sequence; apply intermediate stress-relief heat treatment
High hardenability	Preheat; increase heat input; heat treat without cooling to room temperature
Brittle phases in the microstructure	Solution heat treat prior to welding

Cracks may occur in the weld, the HAZ, or the base metal when the localized stress exceeds the ultimate strength of the metal. Cracks are classified as hot cracks or cold cracks, and may be longitudinal or transverse in their orientation. A *hot crack* is a crack formed at temperatures near the completion of solidification. A *cold crack* is a crack that develops after solidification is complete. Hot cracks propagate between the grains of metal, and cold cracks propagate both between and through the grains of the metal. A *longitudinal crack* is a crack with its major axis oriented approximately parallel to the weld axis. A *transverse crack* is a crack with its major axis oriented approximately perpendicular to the weld axis. See Figure 34-5.

Cracks are classified according to their location in the weld. Crack types in welds are throat cracks, crater cracks, transverse cracks, underbead cracks, lamellar tearing, toe and root cracks, fissures, and liquid metal embrittlement.

Cracks are classified according to their location in the weld.

Crack Types
Figure 34-5

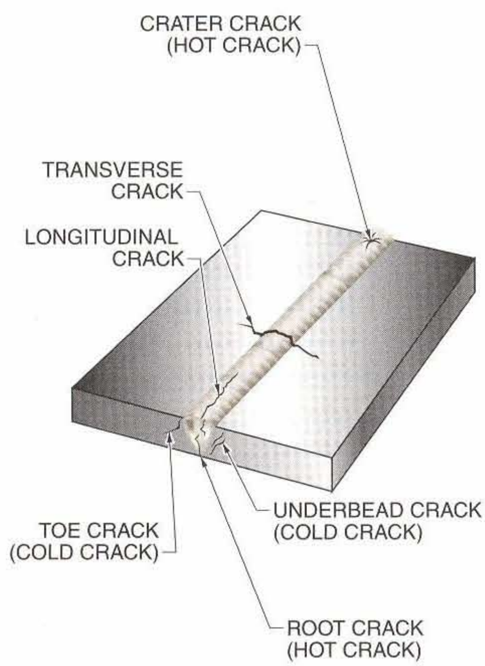


Figure 34-5. *Cracks are classified according to their location in the weld.*

Throat Cracks

Throat cracks are longitudinal cracks in the middle of the surface (throat) of a weld, extending toward the root of the weld. Throat cracks are hot cracks that are confined to the center of the weld. Throat cracks may be the extension through successive weld passes of a crack that started in the first pass (root pass). A throat crack that starts in the root pass and is not removed or completely remelted before deposition of the next pass tends to progress into it and then to each succeeding pass, until it appears at the surface. Final extension of the crack to the surface may also occur during cooling after welding has been completed. See Figure 34-6.

Throat Cracks
Figure 34-6

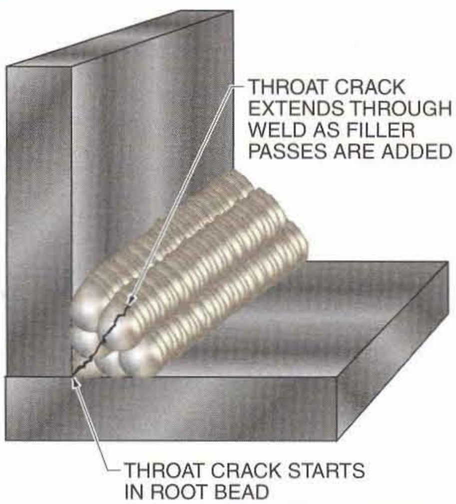


Figure 34-6. *Throat cracks are longitudinal cracks that start in the root bead and extend through the weld as filler passes are added.*

Throat cracks are detected by visual examination or liquid penetrant examination. Throat cracks appear as relatively long, straight cracks along the centerline of the weld. VT is often an adequate method of detection because throat cracks are relatively wide discontinuities.

Throat Crack Prevention. Throat cracks are prevented by using joint designs that reduce joint restraint and excessive stresses in solidifying weld metal. The weld groove dimensions must be adjusted to allow deposition of a sufficient amount of filler metal to overcome excessive joint restraint. The welding process variables must be adjusted to permit correct weld bead size for the joint thickness, sufficient heat input, and optimum travel speed to prevent excessive stresses during solidification. These may also be achieved by factors such as using a more ductile filler metal and reducing cooling rate through application of preheat.

Crater Cracks

Crater cracks are star-shaped cracks which extend from the crater of the weld to the edge of the weld. Crater cracks may be the starting point for throat cracks, particularly when in the crater formed at the completion of a weld. Crater cracks are hot cracks formed by improperly ending the welding arc in the crater of the weld. When the crater is formed elsewhere (for instance, when an electrode is changed), the crack may be welded out when operation resumes. If not, fine star-shaped cracks are observed at various locations. Crater cracks are most often found in materials with high coefficients of expansion such as austenitic stainless steels. See Figure 34-7. Crater cracks are most commonly detected by VT. Crater cracks are clearly visible to the naked eye as star-shaped fissures in the small crater formed at the termination of a weld pass.

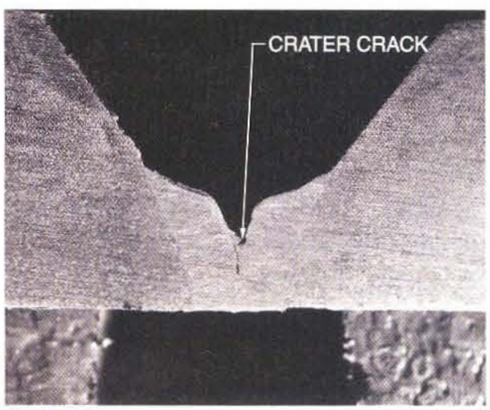


Figure 34-7. *Crater cracks are hot cracks formed from improper termination of the welding arc in the crater of the weld. Crater cracks are commonly found in materials with a high coefficient of expansion.*

Crater Crack Prevention. Crater cracks are prevented by properly terminating the weld. Methods used to prevent cracks include back-stepping the arc into previously solidified material before breaking it, using a foot pedal to allow decay of the arc; filling craters to a slightly convex shape prior to breaking the arc; or using a run-off tab. A *run-off tab* is a piece of metal of the same composition and thickness as the base metal that is tacked to the metal to allow the weld to be completed. The run-off tab is later removed by cutting it off. See Figure 34-8.

Run-off Tabs
Figure 34-8

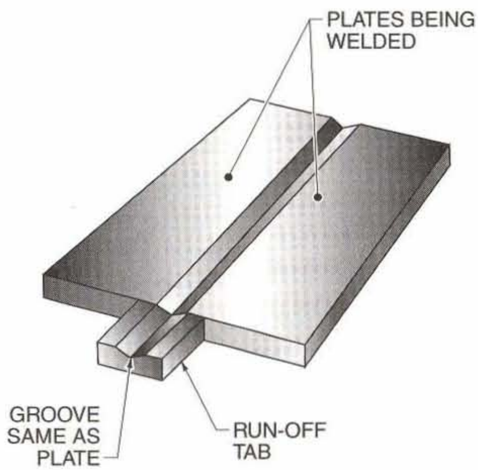


Figure 34-8. *A run-off tab is tack welded to the plates to be welded to allow welding to run off onto it to prevent crater cracks from forming in the weld.*

Transverse Cracks

Transverse cracks are cracks in a weld perpendicular to the axis of the weld and sometimes extending beyond the weld into the base metal. Transverse cracks are cold cracks resulting from high restraint acting on low ductility weld metal. Transverse cracks in steel weldments are usually related to hydrogen embrittlement. Transverse cracks are detected by VT, PT, and MT as tight, relatively straight cracks perpendicular to the weld axis.

Transverse Crack Prevention. Transverse crack prevention depends on the specific welding situation. For example, transverse cracks may be caused by using an incorrect filler metal composition, rapid cooling, or a weld that is too small for the part being joined. Depending on the situation, transverse cracks may be eliminated by using the proper filler metal composition, higher welding current or preheat, or a larger filler metal and final weld dimension, respectively.

Underbead Cracks

Underbead cracks are cracks in the HAZ that generally do not extend to the surface of the base metal. Underbead cracks may be longitudinal or transverse, depending on the direction of the principal stresses in the weldment. Underbead cracks are cold cracks and are usually short and discontinuous. See Figure 34-9.

Underbead Cracks
Figure 34-9

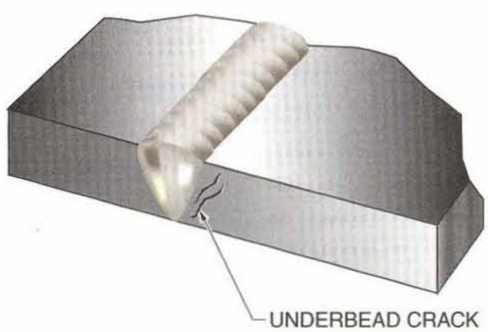


Figure 34-9. *Underbead cracks are cold cracks that form in the heat-affected zone, and generally do not extend to the surface of the base metal.*

Underbead cracks are hydrogen cracks that occur in steels susceptible to hydrogen embrittlement during welding. Dissolved hydrogen, which is released from the electrode or from the base metal, combines with martensite formed in the HAZ during rapid cooling, creating a narrow region that is extremely brittle and sensitive to cracking from residual stresses. Underbead cracks are detected by UT or RT because the crack is usually

below the surface and immediately adjacent the weld. Because of their tightness and short length, underbead cracks may be difficult to detect.

Underbead Crack Prevention. Underbead cracks are prevented by avoiding hydrogen creation in steels that are susceptible to hydrogen embrittlement. Welding conditions that encourage hydrogen creation include poor sheltering of outdoor work that permits rain, snow, or condensation to contact welded areas. Underbead crack prevention is achieved by using low-hydrogen electrodes to join susceptible steels and excluding moisture from electrodes. A drying procedure must be used to remove moisture that can absorb into the coatings on some types of electrodes when exposed to humid atmospheres. The procedure involves storing electrodes in a low-temperature oven, preheating the surface before welding to remove moisture, and postheating immediately to encourage hydrogen to escape. See Figure 34-10.

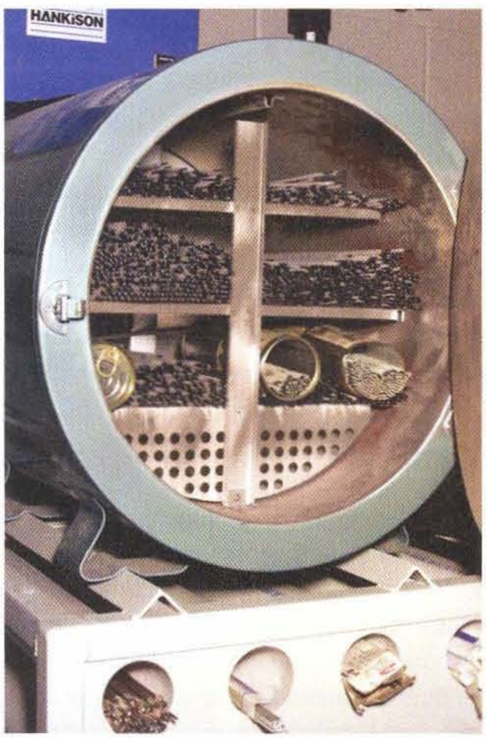


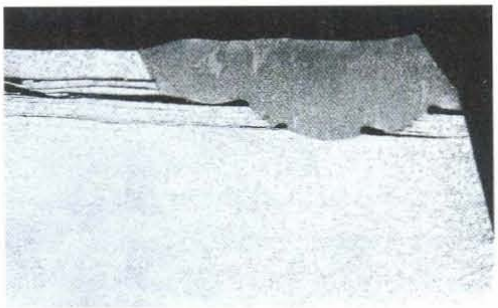
Figure 34-10. *Low-hydrogen electrodes can help prevent underbead cracking. Moisture is removed from electrodes before use by storing the electrodes in an oven.*

Lamellar Tearing

Lamellar tearing is a subsurface terrace and step-like crack pattern in wrought steel base metal oriented parallel to the base metal working direction. Lamellar tearing is caused by tensile stresses in the base metal from welding in a direction perpendicular to the working direction, acting upon nonmetallic inclusions in the base metal parallel to the working direction. Nonmetallic inclusions consist of metallic oxides, sulfides, and silicates that are held in steel. Nonmetallic inclusions are formed during solidification in the steelmaking process from additives to the melt or contamination from refractory in the mold. Hot or cold working elongates nonmetallic inclusions in the working direction if they are plastic at the working temperature. The net result of the elongated nonmetallic inclusions is to decrease through-thickness ductility. This results in lamellar tearing parallel to the direction of the inclusions.

Lamellar tearing is most likely to occur when welding steel plate using groove welds, fillet welds, or combinations of them. T-joints may be especially susceptible to lamellar tearing. See Figure 34-11. The two members of a T-joint are located at approximately right angles to each other in the form of a T. Under these conditions, high tensile stresses can develop perpendicular to the midplane of the steel plate. The magnitude of the tensile stresses depends on the size of the weld, the welding procedure, and the amount of joint restraint imposed by the welding design. Lamellar tearing detection is difficult because it usually does not break to the surface. RT and UT are the most applicable methods for detection of lamellar tearing, which has the appearance of step-like, jagged cracking, with each step nearly parallel to the midplane of the plate.

Figure 34-11. *Lamellar tearing is caused by welding stresses in the base metal perpendicular to the working direction.*



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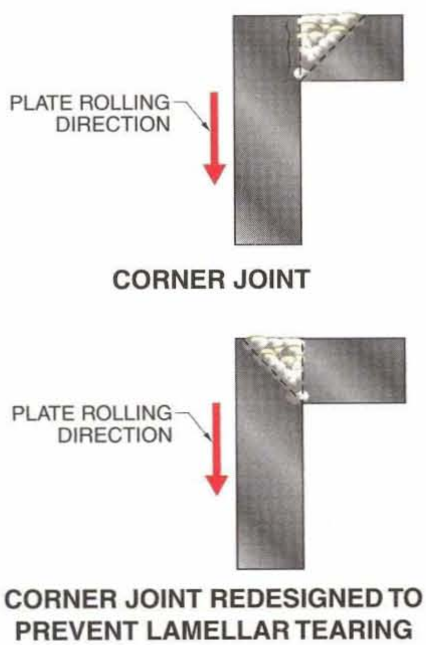
Lamellar Tearing Prevention. Lamellar tearing is prevented most reliably by the use of specially processed steel products that do not contain elongated nonmetallic inclusions. Such steel products are used in critical applications where lamellar tearing is detrimental.

Other methods of reducing lamellar tearing in regular steel products rely on reduction of the stress in the welded joint. See Figure 34-12. These methods include changing the location and/or design of the weld joint to minimize through-thickness strains; using a lower strength weld metal; reducing hydrogen in the weld; using preheat and interpass temperatures of at least 200°F; and peening the weld bead immediately after completion of a weld pass.

Figure 34-12. *The most effective way of preventing lamellar tearing is to redesign the weld joint to minimize stresses on the joint.*

Lamellar Tearing Prevention
Figure 34-12



The chance of lamellar tearing can be reduced by using the correct material, joint design, welding process, and filler metal. Preheating and buttering the joint can also help reduce the risk of tearing.

Toe Cracks and Root Cracks

Toe cracks and root cracks have similar causes but different appearances. Toe cracks are cracks that proceed from the weld toe into the HAZ and base metal. The weld toe is the junction of the weld face and base metal. Root cracks are cracks that proceed into the base metal from the root of a fillet weld. Toe cracks and root cracks are generally cold cracks and initiate in regions of high residual stress. See Figure 34-13. Toe cracks are generally caused by stresses from thermal shrinkage acting on a brittle HAZ. Toe cracks are identified by VT, PT, and MT, and from their location at the weld toe. Root cracks are difficult to detect unless they have propagated through to the opposite side of the base metal.

Toe and Root Crack Prevention. Toe and root crack prevention requires welding procedures and techniques that eliminate embrittlement or excessive stresses in the HAZ of the base metal. With hardenable steels, toe and root crack prevention may be achieved by retarding the cooling rate of the base metal and HAZ with high preheat, or by stress relief after welding with postheat.

Liquid Metal Embrittlement

Liquid metal embrittlement is intergranular penetration (cracking) of the HAZ. *Intergranular penetration* is penetration of molten metal along the grain boundaries of the base metal that leads to embrittlement of the base metal. Liquid metal embrittlement can occur with specific combinations of base metals and liquid metals, usually in the presence of stress. See Figure 34-14.

Toe Cracks & Root Cracks
Figure 34-13

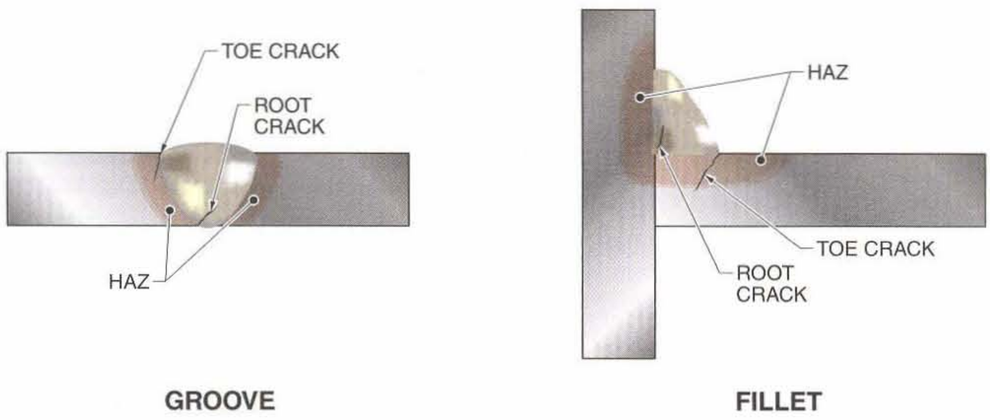


Figure 34-13. *Toe cracks proceed from the weld toe into the heat-affected zone and base metal. Root cracks initiate in regions of high residual stress.*

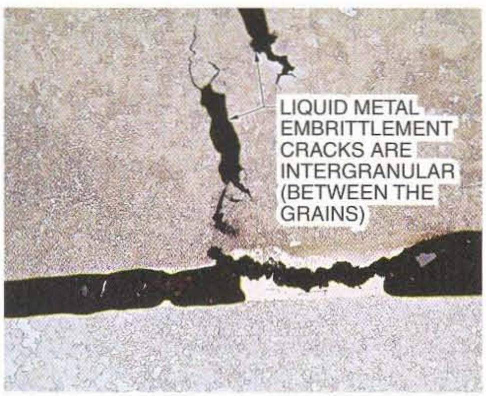


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Figure 34-14. *Liquid metal embrittlement commonly occurs in certain types of metals, usually where a part is exposed to excess stress.*

Brazes are a common cause of liquid metal embrittlement in susceptible alloys. For example, many nickel alloys, when in a stressed condition, may crack from liquid metal embrittlement in contact with molten brazing metal. Liquid metal embrittlement may also occur during welding from contamination of a base metal by other metals. For example, when welding austenitic stainless steels to galvanized steels, zinc contamination may cause liquid metal embrittlement of the austenitic stainless steel base metal. The zinc contamination may be introduced by grinding dust or direct contact between the two metals, such as when welding austenitic stainless steel to galvanized carbon steel. Liquid metal embrittlement may be detected by PT as a relatively wide, jagged crack revealed under magnification.

Liquid Metal Embrittlement Prevention. Liquid metal embrittlement is prevented by avoiding susceptible braze-base metal couples or by ensuring cleanliness of the joint surfaces before welding or brazing. For example, when welding galvanized steel to austenitic stainless steel, all zinc must be removed by grit blasting a minimum of ½″ (13 mm) from the joint face to ensure that the zinc does not melt and mix with the austenitic stainless steel, resulting in liquid metal embrittlement. Liquid metal embrittlement susceptibility may be assessed prior to welding or brazing by testing combinations of weld metal and base metal under simulated joint restraint conditions.

CAVITIES

Cavities are weld discontinuities consisting of rounded holes of various types, either within the weld or at the surface of the weld. Two causes of cavities are gas entrapment during solidification of the weld or contraction (suckback) of the weld during solidification, which cannot be replaced by molten metal. Porosity and wormholes are cavity types formed by gases.

Cavities are rounded discontinuities within a weld or at the surface. The most common type of cavity is porosity.

Shrinkage voids are a cavity type formed by contraction of the weld metal during solidification. See Figure 34-15.

Cavities are usually less serious than cracks because their rounded shape causes significantly lower stress concentration than cracks. Fabrication standards and codes allow certain types of cavities such as porosity, depending on their size, number, and orientation.

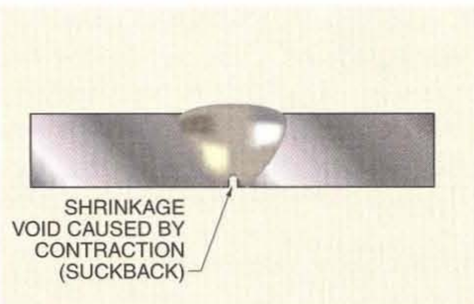

Figure 34-15. *Shrinkage voids are a cavity type formed by contraction (suckback) of the weld metal during solidification.*

Porosity

Porosity consists of cavity-type discontinuities formed by gas entrapment during solidification. See Figure 34-16. Porosity may be surface porosity or subsurface porosity. Surface porosity (blowholes) consists of discrete spherical pits on the surface of the weld. Surface porosity is formed if dissolved gases cannot fully escape before the weld metal solidifies. Surface porosity may be detrimental to fatigue strength if aligned in a direction perpendicular to the direction of stresses.

Subsurface porosity consists of discrete spherical holes within the body of a weld. Subsurface porosity distribution is classified as uniformly scattered, cluster, or linear. Uniformly scattered porosity exhibits a uniform distribution of pores throughout the weld metal, with size varying from almost microscopic to ⅛″ in diameter. Cluster porosity voids occur in the form of clusters separated by considerable lengths of pore-free weld metal. Cluster porosity is associated with changes in welding conditions, such as stopping or starting of the arc. Linear porosity is characterized by an accumulation of pores in a relatively straight line. The number and size of the pores and their linear distribution with respect to the axis of the weld usually define linear porosity. Linear porosity generally occurs in the root pass.

Porosity
Figure 34-16

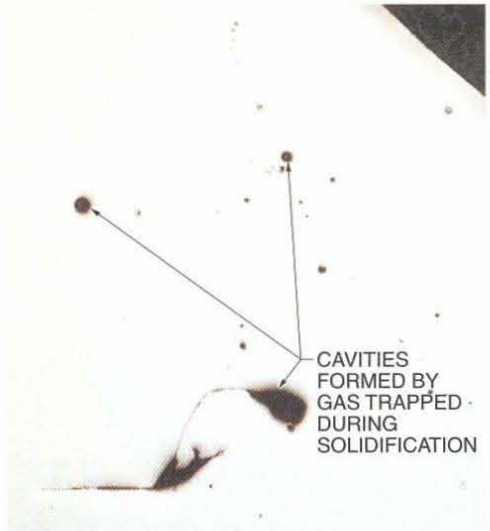

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Figure 34-16. *Porosity is formed by gas entrapment within the weld during solidification if dissolved gases cannot fully escape before the metal solidifies.*

Primary causes of porosity are dirt, rust, and moisture on the surface of the base metal; on the welding consumables; and in the welding equipment.

Porosity is usually the least harmful type of weld discontinuity. Many fabrication standards and codes provide comparison charts that show the amount of porosity that may be acceptable. When porosity exceeds the amount allowable, it must be ground out and repaired. Porosity is detected by RT for internal porosity and by VT or PT for surface porosity. With RT, internal porosity has the appearance of sharply defined dark shadows of rounded contour.

Porosity Prevention. Porosity is prevented by improving welding housekeeping conditions that can cause the porosity. Good housekeeping includes the use of clean materials and well-maintained equipment. Also, avoiding the use

of excessive current and arc lengths can prevent porosity. High currents and excessive arc lengths may cause high consumption of the deoxidizing elements in the covering of shielded metal arc electrodes, leaving insufficient quantities available to combine with the gases in the molten metal during cooling.

Specific methods of preventing porosity depend on the type of welding process. For example, changing welding conditions such as gas flow rate and gas purity for gas shielded processes compensates for improper arc length, welding current, or electrode manipulation. Reducing travel speed may also decrease porosity. See Figure 34-17.

Wormholes

Wormholes are elongated or tubular cavities caused by excessive entrapped gas. Wormholes are detected by RT where they have the appearance of sharply defined dark shadows of rounded or elongated contour, depending on the orientation of the wormholes.

Wormhole Prevention. Wormholes are prevented by methods that are similar to those that prevent porosity.

Shrinkage Voids

Shrinkage voids (pipe or hollow bead) are cavity-type discontinuities normally formed by shrinkage during solidification and are usually in the form of long cavities parallel to the root of the weld. Shrinkage voids are detected by RT.

Shrinkage Void Prevention. Shrinkage voids are prevented by providing sufficient heat input to maintain molten filler metal to all areas of a weld during solidification.

INCLUSIONS

Inclusions are entrapped foreign solid material in deposited weld metal, such as slag or flux, tungsten, or oxide. Inclusion types are slag inclusions, oxide inclusions, and tungsten inclusions. See Appendix.

Inclusions consist of foreign matter in the weld metal, either from the base metal, filler metal, or nonconsumable electrode.

POROSITY PREVENTION	
Problem	**Preventive Measure**
Excessive hydrogen, nitrogen, or oxygen in welding atmosphere	Use low-hydrogen welding process; use filler metals high in deoxidizers; increase shielding gas flow
High solidification rate	Use preheat or increase heat input
Dirty base metal	Clean joint faces and adjacent surfaces
Dirty filler wire	Use specially cleaned and packaged filler wire, and store it in clean area
Improper arc length, welding current, or electrode manipulation	Change welding conditions and techniques
Volatilization of zinc from brass	Use copper-silicon filler metal; reduce heat input
Galvanized steel	Use E6010 electrodes and manipulate the arc heat to volatilize the zinc ahead of the molten weld pool
Excessive moisture in electrode covering or on joint surfaces	Use recommended procedures for baking and storing electrodes Preheat the base metal
High-sulfur base metal	Use electrodes with basic slagging reactions

Figure 34-17. *Porosity prevention methods are determined by the type of welding process; corrective measures are based on the type of problem that has occurred.*

Slag Inclusions

Slag inclusions are nonmetallic materials that are formed by slag reactions and trapped in a weld. Slag is nonmetallic product resulting from mutual dissolution (chemical reactions) of flux and nonmetallic impurities in some welding and brazing processes. Slag inclusions can occur between passes or at the groove face. See Figure 34-18. Slag inclusions may occur in welds made by flux shielded welding processes such as SMAW, FCAW, and SAW. Slag inclusions have a lower specific gravity than the surrounding metal and usually rise to the surface of molten metal, unless they become entrapped in the weld metal.

Figure 34-18. *Slag inclusions are nonmetallic materials formed by slag reactions that are trapped in a weld. Slag inclusions can occur between passes or at the groove face.*

Slag Inclusions
Figure 34-18

Slag inclusions can be prevented by using welding techniques that produce a smooth weld, using the correct current and travel speed, removing slag between each pass, and using wire brushing or light chipping on butt joints or grinding on more difficult joints.

Multiple-pass welds are more prone to slag inclusions than single-pass welds because slag from the preceding pass, if not completely removed, will become entrapped in the subsequent pass. Slag inclusions are detected by RT where they appear as dark lines, more or less interrupted, parallel to the edges of the weld. Slag inclusions are usually elongated and rounded, and run in the direction of the axis of the weld. Slag inclusions can be continuous, intermittent, or randomly spaced.

Slag Inclusion Prevention. Slag inclusions are prevented by using proper welding preparation, such as thoroughly removing slag from the weld and cleaning the weld groove between each pass of a multiple-pass weld. Failure to thoroughly remove slag between each pass increases the probability of slag entrapment and the production of a defective weld. Slag may be removed from the weld surface by chipping, wire brushing, grinding, or air arc gouging. See Figure 34-19.

Complete and efficient slag removal requires that each weld bead be properly contoured and blend smoothly into the adjacent bead or base metal. Small weld beads cool more rapidly than large ones, which tends to make slag removal easier from small beads. Concave or flat beads that blend smoothly into the base metal or any adjoining beads minimize undercutting and avoid a sharp notch along the edge of the bead where slag could stick.

Figure 34-19. *Slag inclusion prevention can be achieved through proper cleaning of the weld groove before depositing additional weld beads. Slag may be removed from the surface by chipping, wire brushing, grinding, or air arc gouging.*

SLAG INCLUSION PREVENTION

Problem	Preventive Measure
Slag inclusions	Clean surface and previous weld bead
Entrapment of refractory oxides	Power wire brush the previous weld bead
Tungsten in the weld metal	Avoid contact between the electrode and the work; use larger electrode
Improper joint design	Increase groove angle of joint
Oxide inclusions	Provide proper gas shielding
Slag flooding ahead of the welding arc	Reposition work to prevent loss of slag control
Poor electrode manipulative technique	Change electrode or flux to improve slag control
Entrapped pieces of electrode covering	Use undamaged electrodes

Oxide Inclusions

Oxide inclusions are particles of surface oxides on the base metal or weld filler metal that have not melted and mix with the weld metal. Oxide inclusions occur when welding metals that have tenacious surface oxide films, such as stainless steels, aluminum alloys, and titanium alloys. Oxide inclusions are detected by RT.

Oxide Inclusion Prevention. Oxide inclusion prevention is achieved by cleaning out the joint and weld area thoroughly before welding. See Figure 34-20. The weld area should be thoroughly cleaned after each pass using a wire brush.

Oxide Inclusion Prevention
Figure 34-20

Figure 34-20. *Oxide inclusions can be prevented by cleaning out the joint and weld area thoroughly before welding.*

Tungsten Inclusions

Tungsten inclusions are particles from the nonconsumable tungsten electrode that enter the weld. See Figure 34-21. The occasional contact between the electrode and the work or the molten metal may transfer particles of the tungsten into the weld deposit. A limited number of tungsten inclusions may be acceptable according to the applicable fabrication standard or code, but it will depend on the thickness of the part being welded. Tungsten inclusions are detected by VT or RT. VT is used for tungsten inclusions at the surface. However, as with most other types of inclusions, tungsten inclusions are generally detected using RT, where they appear as isolated, sharp, irregular shapes.

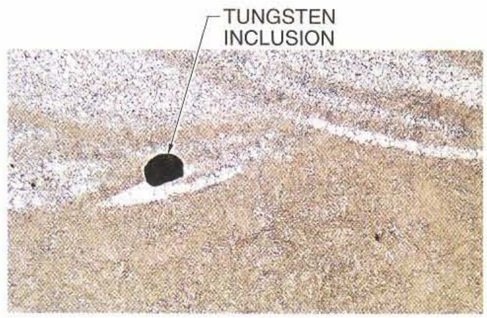

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Figure 34-21. *Tungsten inclusions are particles found in the weld metal as a result of the nonconsumable tungsten electrode coming in contact with the work or the molten metal.*

Tungsten Inclusion Prevention. Tungsten inclusions are prevented at the weld start using superimposed high-frequency current for arc starting and a copper striker plate. Tungsten inclusions may be minimized by using thoriated tungsten or zirconium-tungsten electrodes and less current or larger electrodes, and by keeping the tungsten electrode out of the molten weld pool.

INCOMPLETE FUSION AND INCOMPLETE PENETRATION

Incomplete fusion (lack of fusion) and incomplete joint penetration (lack of penetration) are similar discontinuities. They result from incomplete melting at the interface between weld passes or in the root of the joint.

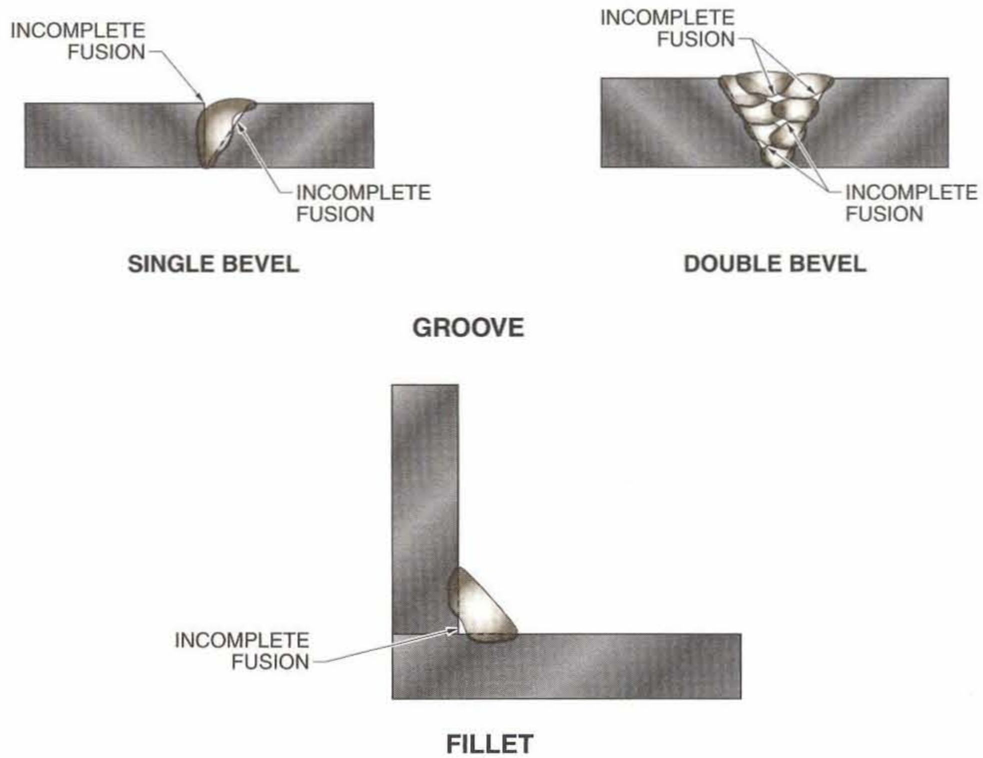
Incomplete fusion and incomplete penetration are found in areas with incomplete melting between the base metal and the weld metal. Incomplete fusion is less desirable than incomplete penetration.

Incomplete Fusion

Incomplete fusion is a lack of union (fusion) between adjacent weld passes or base metal. Incomplete fusion may be caused by failure to raise the temperature of the surface layers of base metal or previously deposited weld metal to the melting temperature. Incomplete fusion is usually elongated in the direction of welding, with either sharp or rounded edges. See Figure 34-22.

Figure 34-22. *Incomplete fusion results when adjacent passes fail to meld properly. It can be caused by a failure to sufficiently raise the temperature of the surface layers of the base metal or deposited metal.*

Incomplete Fusion
Figure 34-22



Incomplete fusion occurs more commonly with some welding processes than with others. For example, the reduced heat input in the short circuiting transfer mode of GMAW results in low penetration into the base metal. This may be desirable on thin-gauge materials and for out-of-position welding, but may result in incomplete fusion, especially in the root area or along groove faces. Incomplete fusion leads to undesirable stresses and its admissibility is severely restricted in most fabrication standards and codes.

Incomplete fusion can be detected by RT as a thin, dark line with sharply defined edges. Depending on the orientation of the defect with respect to the X-ray beam, the line may tend to be wavy and diffuse. However, some codes may not permit RT as a means of qualifying welders when using GMAW short circuiting transfer on test welds.

Incomplete Fusion Prevention. Incomplete fusion is prevented by ensuring an adequate surface temperature to raise the temperature of the surface layers to the melting point, which allows the deposited metal to fuse with the surface below it. This may be achieved by reducing travel speed, increasing welding current or increasing electrode diameter, using joint design to allow electrode accessibility to all surfaces within the joint, use of proper electrode angle, and reducing the effects of arc blow. See Figure 34-23.

Incomplete Penetration

Incomplete penetration is a condition in a groove weld in which weld metal does not extend through the joint thickness. In arc welding, the arc is established between the electrode and closest part of the base metal. All other areas of the base metal receive heat principally by conduction. If the region of base metal closest to the electrode is a considerable distance from the joint root, heat conduction may be insufficient to attain adequate temperature to achieve fusion of the root. See Figure 34-24.

INCOMPLETE FUSION PREVENTION	
Problem	**Preventive Measure**
Insufficient heat input	Use correct type or size of electrode; proper joint design; and proper gas shielding
Incorrect electrode position	Maintain proper electrode position
Weld metal running ahead of the arc	Reposition work; lower current; increase weld travel speed
Trapped oxides or slag on weld groove or weld face	Clean weld surface prior to welding

Figure 34-23. *Incomplete fusion prevention can be ensured using the proper welding parameters.*

Incomplete Penetration
Figure 34-24

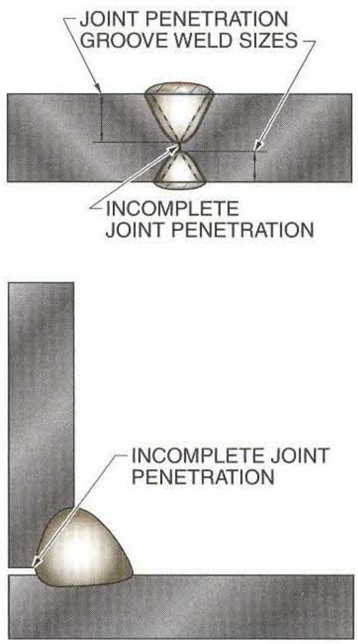


Figure 34-24. *Incomplete joint penetration occurs when weld metal does not penetrate completely through the joint thickness. It can occur when the base metal is a considerable distance from the heat of the electrode.*

Incomplete penetration is not always undesirable because some weld joints are designed for partial penetration. The applicable fabrication standards and codes indicate permissible levels of incomplete penetration. Incomplete penetration is detected by RT, where it appears as a dark, continuous or intermittent line in the middle of the weld.

Incomplete penetration may occur when a groove is welded from one side only if the root face dimension is too great, if the root opening is too small, or if the groove angle of the V-groove is too small, even with an adequate root opening and a satisfactory joint design. Incomplete penetration may also be caused by electrodes that are too large or that have a tendency to bridge; or by using abnormally high rates of travel or insufficient welding current.

Incomplete Penetration Prevention. The most frequent cause of incomplete penetration is the use of an unsuitable joint design for the welding process or the conditions of the actual weld construction. Unsuitable joint designs make it difficult to reproduce qualification test results under conditions of actual production. See Figure 34-25.

INCORRECT SHAPE

An incorrect shape in a weld includes any weld discontinuity that produces an unacceptable weld profile or dimensional nonconformance and that adversely influences performance of the weld under load. An insufficient cross-sectional area of a weld may result in a weld that is unable to support a load, or may allow a stress-concentrating notch, leading to fracture. Incorrect shape discontinuities are undercut, overlap, excessive weld reinforcement, underfill, concave root surface, and melt-through.

Incorrect shapes, such as undercut, overlap, excess weld reinforcement, underfill, concave root surface, and melt-through, produce an unacceptable weld profile.

Figure 34-25. *Using a proper joint design can help ensure that incomplete joint penetration does not occur in a weld.*

INCOMPLETE PENETRATION PREVENTION	
Problem	**Preventive Measure**
Excessively thick root face or insufficient root opening	Use proper joint geometry
Insufficient heat input	Follow welding procedure
Slag flooding ahead of arc	Adjust electrode or work position
Electrode diameter too large	Use smaller electrode or increase root opening
Misalignment of second side weld	Improve visibility or backgouge weld
Failure to backgouge when specified	Backgouge to sound metal if required in welding procedure specification
Bridging of root opening	Use wider root opening or smaller electrode in root pass

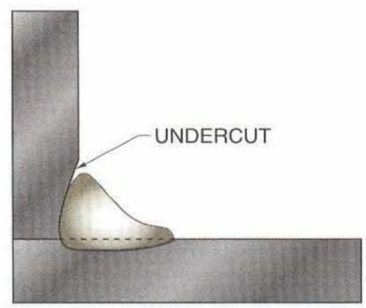
Undercut

Undercut is a groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal. See Figure 34-26. Faulty electrode manipulation, excessive welding current, excessive arc length, excessive travel speed, and arc blow cause undercut. Undercut of a completed weld is undesirable because it produces a stress concentration that reduces impact strength and fatigue resistance. Undercut is detected by VT in groove or fillet welds. VT is the simplest and most effective way of detecting and measuring undercut against the particular fabrication code. RT may also detect undercut in groove welds, where it appears as a dark line, sometimes broad and diffuse, along the edge of the weld.

Undercut Prevention. Undercut is prevented by the following methods: pausing at each side of the weld bead when using the weave bead technique; using proper electrode angles; using proper welding current for electrode size and welding position; reducing arc length; reducing travel speed; and reducing the effects of arc blow. See Appendix.

Undercut of the sidewalls of a welding groove will in no way affect the completed weld if it is removed before the next bead is deposited in that location. A well-rounded chipping tool or grinding wheel will be required to remove the undercut. If the undercut is slight, however, it is possible for the welder to estimate how deeply the weld will penetrate and fill the undercut with the next pass.

Undercut
Figure 34-26



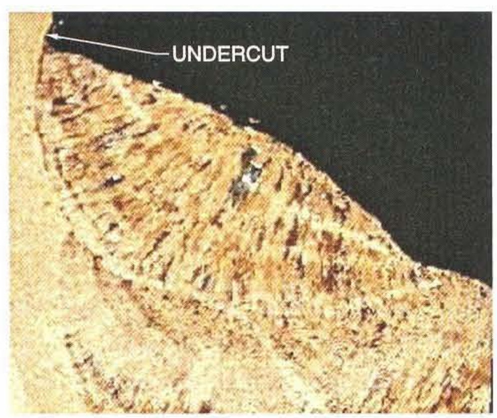


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Figure 34-26. *Undercut occurs when a groove is melted into the base metal adjacent to the weld toe and is left unfilled by weld metal.*

Undercut is sometimes repaired by grinding and blending or welding. Grinding should be performed with a pencil-type grinder, and the grinding marks should be transverse to the length of the weld with a 250 microinch finish or better.

Overlap

Overlap is protrusion of weld metal built up beyond the weld toe or weld root. Overlap is an area of incomplete fusion that creates a stress concentration and can initiate premature failure under load. See Figure 34-27. Overlap is detected by VT. Overlap is considered a defect that must be removed by grinding according to the applicable fabrication standard or code.

Overlap
Figure 34-27

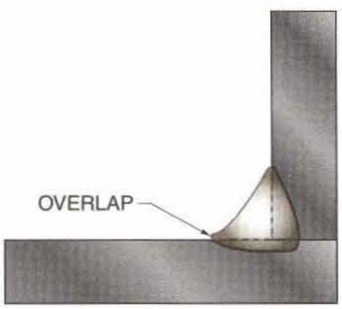


Figure 34-27. *Overlap is a protrusion of weld metal built up beyond the weld toe or the weld root.*

Overlap Prevention. Overlap is prevented by using a higher travel speed or welding current, reducing the electrode diameter, or changing the electrode angle so that the force of the arc will not push molten weld metal over unfused sections of base metal. See Appendix.

The most common reason for overlap is welding with the current set too low. If overlap occurs, first check for the proper current level.

Excess Weld Reinforcement

Excess weld reinforcement is weld metal built up in excess of the quantity required to fill a joint. Excess weld reinforcement can be of two types—excess face reinforcement or excess root reinforcement. See Figure 34-28.

Excess Weld Reinforcement
Figure 34-28

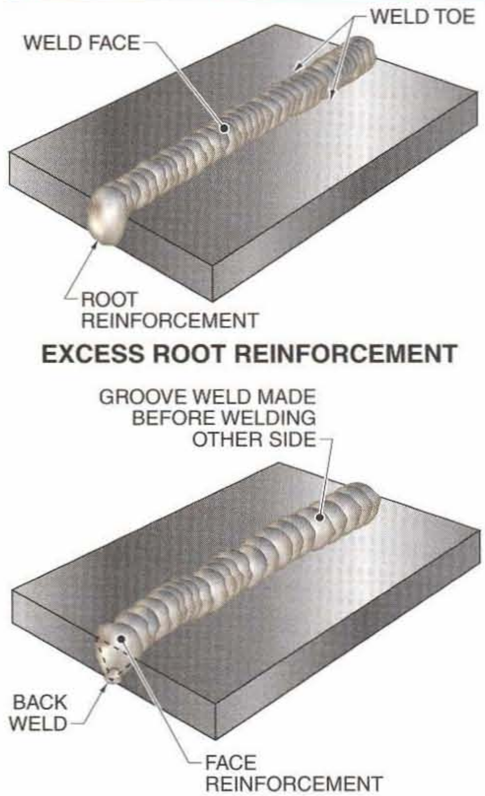


Figure 34-28. *Excess weld reinforcement, while not a severe discontinuity, can excessively stiffen a section of metal, causing stress concentrations at the base. It is also more expensive due to the increased amount of filler metal needed, and can have an objectionable appearance.*

Filler metal added to make a weld must be as thick as the base metal. Slightly thicker filler metal is usually permitted to allow for discontinuities and to avoid the cost penalty associated with grinding the weld metal flush with the base metal. Excess weld reinforcement, though not as severe as overlap, is undesirable because it thickens and stiffens the section and establishes a stress concentration at the junction with the base metal. The stress-concentrating effect is more severe for fillet welds than for butt welds. Excess weld reinforcement is economically unsound and objectionable from the appearance point of view.

Fabrication standards and codes usually limit the allowable amount of excess weld reinforcement. Various welding codes impose a maximum amount of reinforcement for the thickness of the material being welded. Thicknesses may vary from 1/16″ to 7/32″. Excess weld reinforcement is detected by VT. If considered a defect, it must be removed by grinding.

Excess Weld Reinforcement Prevention. Excess weld reinforcement is prevented by use of the correct welding current, proper welding technique, and appropriate number of weld passes to fill the joint.

Underfill
Figure 34-29

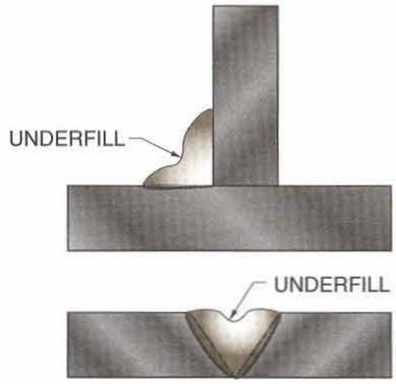


Figure 34-29. *Underfill is a discontinuity that extends below the adjacent surface of the base metal.*

Underfill

Underfill is a discontinuity in which the weld face or root surface extends below the adjacent surface of the base metal. Underfill reduces the cross-sectional area of the weld below the amount required in the design. See Figure 34-29. Underfill tends to occur primarily in the flat position in fillet welding and in the 5G and 6G pipe groove welding positions. Underfill creates a region susceptible to structural failure from insufficient cross section to support the load. In fillet welds, underfill is exhibited by a less than normal throat as measured by the length of the leg. Underfill is detected by VT.

Underfill Prevention. Underfill is prevented by reducing welding current and voltage, reducing arc length and arc travel speed, and adding sufficient filler metal.

Concave Root Surface

A *concave root surface* is a depression in the weld extending below the surface of the adjacent base metal caused by an underfill in the root pass of a weld. Concave root surface is detected by RT. If considered a defect, the surface may be suitably prepared or cleaned and additional weld metal added.

Concave Root Surface Prevention. Concave root surfaces are prevented in butt welds by reducing the root opening of the weld.

Melt-Through

Melt-through also called burn-through, is a discontinuity that occurs in butt welds when the arc melts through the bottom of the weld. Melt-through is different than melt-thru, which is visible root reinforcement produced in a joint that is welded from one side. See Figure 34-30. Melt-thru is often specified; melt-through is a discontinuity or defect. Melt-through is detected by RT as a region of excessive thickness (lower density) in the region of the weld root.

Melt-Through Prevention. Melt-through is prevented in butt welds by reducing the welding current and width of the root opening, and by increasing the arc travel speed.

MISCELLANEOUS DISCONTINUITIES

Miscellaneous discontinuities include weld discontinuities that do not fit into other categories of discontinuities. Miscellaneous discontinuities include arc strikes and spatter.

Melt-Through
Figure 34-30

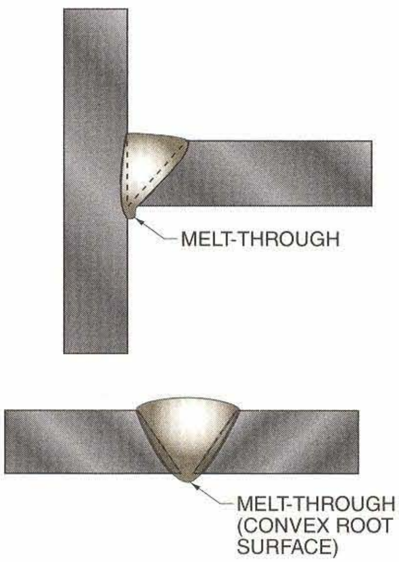


Figure 34-30. *Melt-through is a discontinuity produced in a joint when the arc melts through the bottom of the weld.*

Arc Strikes

An *arc strike* is a discontinuity that results from arcing of the electrode and consists of any localized remelted metal, heat-affected metal, or change in the surface profile of any base metal. Arc strikes may be depressions or marks that occur on the surface of the weld by the welder accidentally striking the electrode on the base metal adjacent to the weld. Arc strikes may degrade base metal properties on hardenable steels like medium-carbon steels or low-alloy steels and may form a region of brittle martensite from the rapid quenching effect of the high temperature. See Figure 34-31. Arc strike detection is achieved by VT. Some fabrication standards and codes require arc strikes to be ground to a smooth contour and inspected to ensure soundness by an appropriate NDE test such as PT or MT.

Arc Strike Prevention. Arc strikes are prevented for certain types of work, such as pipe, by placing protective wrappings around the part to prevent accidental contact with the electrode.

Arc Strikes
Figure 34-31

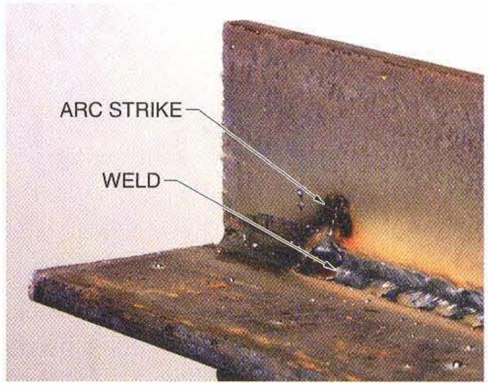


Figure 34-31. *An arc strike results when the electrode strikes the base metal during welding, and it can degrade base metal properties.*

Spatter

Spatter is a discontinuity that occurs when metal particles are expelled during fusion welding and do not form part of the weld. Spatter appears as droplets of solidified weld metal on the base metal adjacent to the weld. See Figure 34-32. Spatter detection is achieved by VT.

Spatter
Figure 34-32

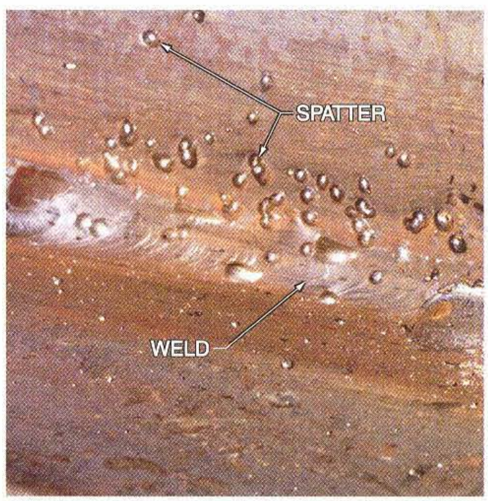


Figure 34-32. *Spatter appears as droplets of solidified weld metal on the base metal adjacent to the weld.*

Spatter Prevention. Spatter can be reduced or prevented by reducing the welding current, reducing the effect of arc blow, reducing the arc length, and ensuring the use of clean and undamaged electrodes. See Appendix. Anti-spatter spray is available for prevention of spatter for many welding applications.

Arc strikes may degrade base metal properties on hardenable steels like medium-carbon steels or low-alloy steels and may form a region of brittle martensite from the rapid quenching effect of the high temperature.

POINTS TO REMEMBER

1. A discontinuity is an interruption in the structure of a weld. Discontinuities are not always defects.
2. Discontinuities are classified as defects when they exceed the minimum requirements permitted by the controlling code or standard.
3. Weld stresses may be concentrated or enhanced by the presence of discontinuities, leading to failure under load.
4. Cracks are fracture-type discontinuities and are not permitted in fabrication standards and codes.
5. Cracks are classified according to their location in the weld.
6. Cavities are rounded discontinuities within a weld or at the surface. The most common type of cavity is porosity.
7. Inclusions consist of foreign matter in the weld metal, either from the base metal, filler metal, or nonconsumable electrode.
8. Incomplete fusion and incomplete penetration are found in areas with incomplete melting between the base metal and the weld metal. Incomplete fusion is less desirable than incomplete penetration.
9. Incorrect shapes, such as undercut, overlap, excess weld reinforcement, underfill, concave root surface, and melt-through, produce an unacceptable weld profile.
10. Arc strikes may degrade base metal properties on hardenable steels like medium-carbon steels or low-alloy steels and may form a region of brittle martensite from the rapid quenching effect of the high temperature.

QUESTIONS FOR STUDY AND DISCUSSION

1. How can weld joint design be adjusted to prevent throat cracks?
2. How do crater cracks form?
3. How can crater cracks be prevented?
4. What causes toe cracks?
5. How can toe and root cracks be prevented?
6. What are the two main types of porosity?
7. What can be done to reduce porosity in a weld?
8. What are slag inclusions?
9. How can slag inclusions be prevented in multiple pass welds?
10. What causes tungsten inclusions?
11. Which process is more likely to produce incomplete fusion: SMAW or GMAW in short circuiting mode, and why?
12. What causes incomplete penetration?
13. What is overlap, and how can it be prevented?
14. What is melt-through, and how can it be prevented?
15. Why are arc strikes detrimental to medium-carbon or low-alloy steels?

Welding Procedure Qualification 35

Welding procedure qualification encompasses not only the legal requirements of the applicable fabrication standard or code, but also the directions for making a consistent weld. Welding procedure qualification variables affect the weld and must be specified.

Welding procedure qualification determines, by preparation and testing of standard specimens, whether welding in accordance with a welding procedure specification (WPS) will produce sound welds and adequate joint properties. A WPS provides formal documentation for all qualified welding variables.

A procedure qualification record (PQR) determines, by preparation and testing of standards specimens, whether welding in accordance with a WPS will produce sound welds and adequate joint properties. Much of the data required by the PQR is the same information required in the WPS.

WELDING PROCEDURE QUALIFICATION

Welding procedures used by welders and welding operators require qualification to be in accordance with fabrication standards and codes. Welding procedure qualification encompasses not only the legal requirements of the applicable fabrication standard or code but also the directions for making a consistent, quality joint and weld. Differences, however subtle, between the requirements of various fabrication standards and codes make it essential that the applicable document be consulted for guidance.

Qualified welding procedures consist of welding procedure specifications (WPS) and procedure qualification records (PQR). Both WPS and PQR define applicable welding variables. See Appendix.

WELDING PROCEDURE QUALIFICATION VARIABLES

A *welding procedure qualification variable* is an essential condition (parameter) that affects the integrity of a weld joint. Welding procedure qualification variables must be indicated in the welding procedure qualification record. Essential variables are listed in the applicable fabrication standard or code. Welding procedure qualification variables for arc welding may consist of any or all of the following:

- welding process
- joint design
- base metal
- filler metal
- welding position
- preheat, interpass temperature control, and postheating
- shielding gas
- electrical characteristics
- welding technique

Oxyfuel welding, brazing, surfacing weld, and resistance welding require additional welding procedure qualification variables.

Welding Processes

Certain welding processes cannot be used with specific metals because the welding process used may affect the weldability of the metal. For example, titanium alloys are not typically welded

Qualified welding procedures consist of the welding procedure specification (WPS) and the procedure qualification record (PQR).

Welding procedure qualification variables are welding parameters that affect the integrity of a weld joint and must be indicated in the PQR.

Joint design is an example of a procedure qualification variable and may encompass weld type, edge preparation, and method of preparing the edge.

⚠ WARNING

Gloves are not usually worn when grinding. The hand can be drawn into the grinder if the glove gets caught.

by flux shielded welding processes such as SMAW. Titanium alloys are most often welded by gas shielded welding processes such as GMAW, GTAW, or RW.

Welding procedure specifications are typically developed by a welding engineer who has previous experience with the particular weld parameters, and who uses recommendations by suppliers of welding equipment such as the base metal, welding machine, and filler metals. The welding procedure specification must also meet applicable codes.

Joint Design

Joint design is the shape, dimensions, and configuration of the joint. The joint is the junction of members or the edges of members that are to be joined. An effective joint design achieves welding at minimal cost. The joint design influences how much filler metal may be required to fill a joint, and the ease of adding filler metal. Welding procedure variables that affect joint design are weld type, edge preparation, and backgouging.

Weld Type. *Weld type* is the cross-sectional shape of the weld after filler metal is added to the joint. Basic weld types are groove weld and fillet weld. Each weld type can have several different configurations.

Edge Preparation. *Edge Preparation* is the preparation of the workpiece edges by cutting, cleaning, or other methods. All fillet weld configurations can be made without additional edge preparation. Three groove weld configurations can be made without additional edge preparation. They are square groove, flare V-groove, and flare bevel groove. Edge preparation is done by shearing, thermal cutting, grinding, machining, or backgouging.

Shearing is the parting of material when one blade forces the material past an opposing blade. Shearing produces a square groove. Shearing is the most economical method of edge preparation and is used for sheet metal.

Thermal (flame) cutting consists of a group of processes that remove metal by rapid oxidation. Thermal cutting is the most common method of edge preparation, and is used for most work with thickness greater than sheet metal. Thermal cutting is versatile and economical and may be manipulated to produce both square edges and added bevels. The heat produced by thermal cutting may alter the metallurgical structure of some metals. In such cases, the thermally cut surface must be dressed by grinding to remove a minimum of 1/8″ of affected base metal before any welding is performed.

Grinding is the mechanical removal of metal from the surface using hard, brittle grains of an abrasive material. Grinding is usually performed with a grinding wheel. Grinding is used for medium thicknesses of material and may be tooled up to provide reproducible geometries. See Figure 35-1.

Machining is precise shaping to a desired profile using special tools to remove material. Machining is used on thick-wall components to prepare J- and U-grooves and on circular components of all diameters and wall thicknesses. Machining is an accurate, final method of edge preparation.

Grinding
Figure 35-1

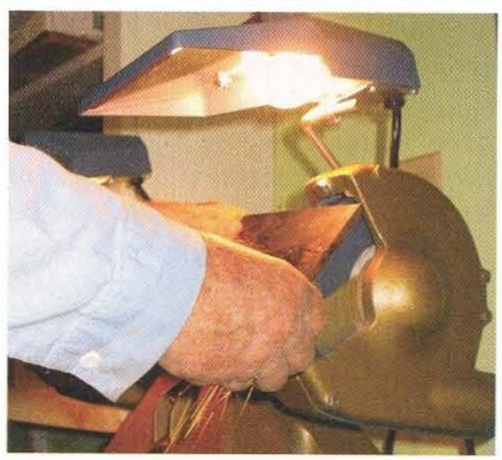


Figure 35-1. *Grinding is used for medium thicknesses of material to remove metal from the surface.*

Backgouging. *Backgouging* is the removal of weld metal and base metal from the weld root side of a welded joint to facilitate complete fusion and complete joint penetration when welding on that side is completed.

Backgouging is done when joints are welded from both sides and is used to produce final joints free from cracks and other unsound conditions. The backgouging method must be indicated on drawings when joints are to be welded from both sides. If backgouging requires an inspection method other than visual, the method should be indicated on the drawings. Methods of backgouging include chipping, grinding, air carbon arc gouging, or oxyfuel gouging. See Figure 35-2.

Base Metal

The base metal(s) must be properly identified. Two methods may be used: the base metal material specification and the base metal weldability classification. The base metal thickness range is also indicated.

Base Metal Material Specifications. A *base metal material specification* is the chemical composition or industry specification of the base metal. Any special condition of the base metal, such as heat treatment, cold working, or special cleaning must be indicated if it affects the metal's weldability, or if welding alters the base metal properties. For example, localized welding reduces the strength of a cold-worked metal in the heat-affected zone. The fact that the metal is cold-worked must be indicated on the drawings.

Base Metal Weldability Classifications. The *base metal weldability classification* is an alphanumeric system that groups base metals with similar welding characteristics. A welding procedure that provides excellent results with one base metal classification may prove completely inadequate with another classification. The base metal classification system assigns a number to a base metal according to its chemical composition, weldability, and mechanical properties.

Base metals are grouped by weldability classifications to reduce the number of procedure qualification variables. Base metals with the same weldability classification may be substituted for one another with no effect.

Backgouging
Figure 35-2

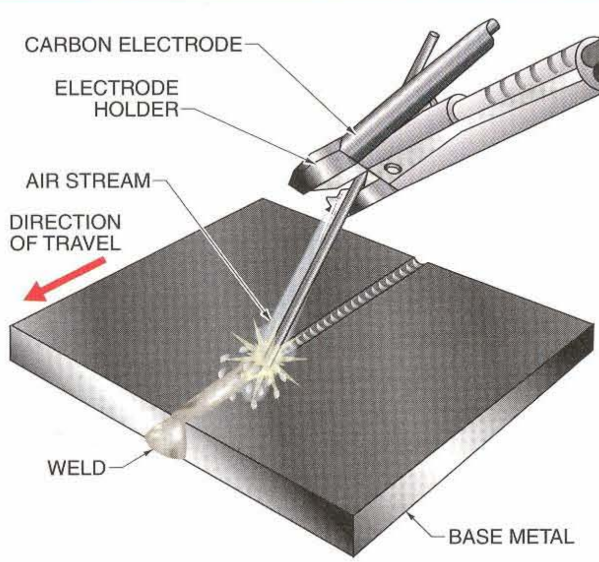


Figure 35-2. *Backgouging is performed to improve the quality of the root pass.*

In the ASME Boiler and Pressure Vessel Code, base metal weldability classification consists of P-numbers assigned to base metals to indicate their characteristics. P-numbers are described in Section IX of the ASME Boiler and Pressure Vessel Code. Metals with the same P-number are covered under the same WPS. For example, P1 materials are low-carbon steels that generally do not require preheat. P4 materials are specific chrome-moly steels that require preheat to approximately 300°F. Welding procedures are qualified by grouping base metals according to their P-number, which reduces the number of welding procedure qualifications required. See Figure 35-3.

Base Metal Thickness Ranges. The *base metal thickness range* is a procedure qualification variable that indicates the range of base metal thicknesses covered in the procedure qualification record. For pipe, the pipe diameter range and pipe wall thickness must be indicated. In most cases, base metal thickness range is 1⁄16″ or 3⁄16″ to 2T, where T is the thickness of the test sample weld.

Filler Metal

Filler metal variables that must be considered are filler metal specification, filler metal usability classification, filler metal diameter, and filler metal quantity. A separate filler metal description is required for tack welding.

Filler Metal Specifications. *Filler metal specification* is identification of filler metal by AWS number or other specification designation. If required by the applicable fabrication standard or code, more details may be needed. Additional required information may include manufacturer; heat; lot or batch number of the filler metal or other welding consumable; and the results of supplementary identification such as X-ray fluorescence (XRF) analysis.

Filler Metal Usability Classifications. The *filler metal usability classification* is an alphanumeric method of grouping filler metals with similar characteristics. In AWS specifications and the ASME Boiler and Pressure Vessel Code, filler metals are given F-numbers to indicate their grouping. Filler metals

Figure 35-3. *P-numbers reduce the number of welding procedures that must be developed by grouping metals that have similar weldability characteristics.*

P-NUMBERS

Spec. No.	Embedded Type & Grade	Welding P-No.	Brazing P-No.	Nominal Comp.	Product Form
SA-36	—	1	—	C-Mn-Si	Plate
SA-53*	Type E Gr. B	1	101	C-Mn	ERW Pipe
SA-53*	Type S Gr. B	1	101	C-Mn	Smls Pipe
SA-105	—	1	101	C-Si	Pipe Flange
SA-106	B	1	101	C-Si	Smls Pipe
A108	1018 CW	—	—	C	Bar
A134	A 285 B	—	—	C	Welded Pipe
SA-182†	F11, Cl. 2	4	102	1¼ Cr-Mo	Forging
SA-182†	F22, Cl. 1	5A	102	2¼ Cr-Mo	Forging
SA-182†	F304L	8	102	18Cr-8Ni	Forging < 5″
A211	A570 Gr. 30	—	—	C	Welded Pipe
SA-234	WPB	1	101	C-Si	Pipe Fitting
SA-234	WP5	5B	102	5Cr-Mo	Pipe
SA-240	Type 304L	8	102	18Cr-8Ni	Plate
SA-335	P22	5A	102	2¼ Cr-1Mo	Smls Pipe
SA-387	11,Cl. 1	4	102	1¼ Cr-½Mo	Plate
SA-516	Grade 60	1	101	C-Mn-Si	Plate
API5L	Grade B	—	—	C-Mn	Smls/welded

* Sa-53 specifications have same UNS Number, but are different product forms.
† Materials have same specification number, but different nominal compositions.

with the same usability classification (F-numbers) generally may be substituted for one another, reducing the number of welding procedure specifications required. For ferrous weld metal, analysis numbers, or A-numbers, are additionally assigned to further segregate F-numbers. A-numbers, which range from 1-12, represent classifications of ferrous weld metal analysis for procedure qualification. A-numbers are essential variables for most welding processes. Filler metals with the same usability classification and the same A-numbers may be welded with the same welding procedure. See Figure 35-4. Filler metals with the same usability classification and different A-number require a new WPS to be qualified.

Filler Metal Diameter. The filler metal diameter influences welding current requirements and joint penetration ability. If the root opening is too tight, the groove angle too narrow, or the filler metal diameter too large, the welding electrode will not be able to deposit the weld metal at the root. Small-diameter filler metal is often required for the root pass to eliminate the chances of incomplete penetration, to prevent melt-through, and for heat control. Small-diameter filler metals also require less current than larger diameter filler metal. Filler metal diameter(s) required for welding different thicknesses of metal in different positions are also indicated.

Filler Metal Quantity. *Filler metal quantity* is the deposited weld metal thickness range for groove or fillet welds. Filler metal quantity is usually indicated by a sketch showing the location of each weld pass in the joint. The correct amount of deposited weld metal achieves the required joint

Filler metals are grouped by usability classification to reduce the number of procedure qualification variables. Filler metals with the same usability classification may be substituted for one another with no effect.

A- AND F-NUMBERS

A-Numbers

A-Number	Type of Weld Deposit	Analysis C*	Cr*	Mo*	Ni*	Mn*	Mn*
1	Mild Steel	.15	—	—	—	1.60	1
2	Carbon-Moly	.15	.50	.4 – .65	—	1.60	1
3	Cr-Mo (.4% to 2%)	.15	.40 – 2	.4 – .65	—	1.60	1
4	Cr-Mo (2% to 6%)	.15	2 – 6	.4 – .65	—	1.60	2

F-Numbers (Electrode and Welding Rod Groups for Qualification)

F-Number	ASME Specification Number	AWS Classification Number	
1	SFA-5.1 and 5.5	EXX 20, EXX 22, EXX 24, EXX 27, EXX 28	
	SFA-5.4	EXX 25, EXX 26	
2	SFA-5.1 and 5.5	EXX 12, EXX 13, EXX 14, EXX 19	
3	SFA-5.1 and 5.5	EXX 10, EXX 11	
4	SFA-5.1 and 5.5	EXX 15, EXX 16, EXX 18, EXX 48	
	SFA-5.4 (other than austenitic and duplex)	EXX 15, EXX 16	
5	SFA-5.4 (austenitic and duplex)	EXX 15, EXX 16	
6	SFA-5.9	GTAW	ERXX
	SFA-5.17	SAW	FXX-EXX
	SFA-5.18	GMAW	ERXXS-X
	SFA-5.20	FCAW	EXXT-X
2X	Aluminum	GTAW	ER 4043
3X	Copper	GTAW	ER CuNi
4X	Nickel	SMAW	ENiCrFe-3
5X	Titanium	GTAW	ERTi-7
6X	Zirconium	GTAW	ERZr3
7X	Weld Overlay	SMAW	EXXX-X

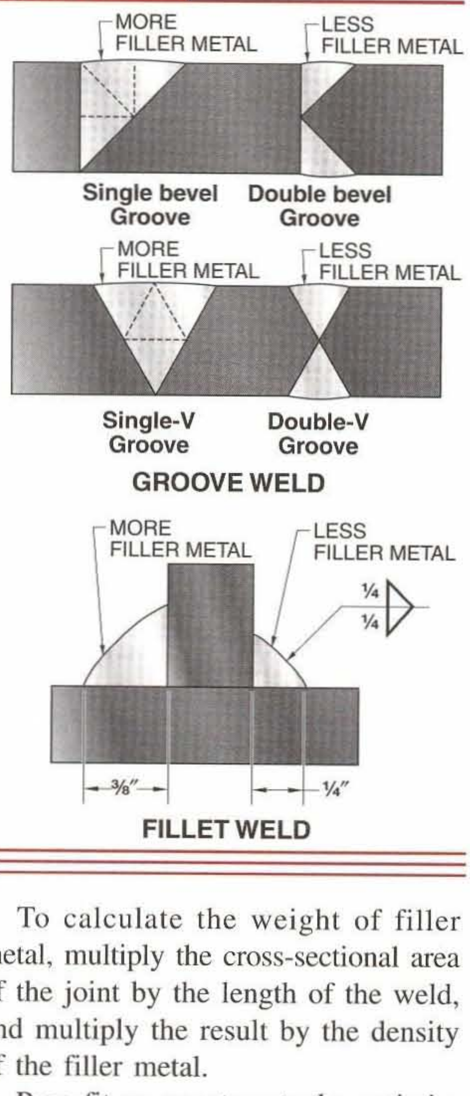
* in percent (%)

Figure 35-4. *A- and F- numbers reduce the number of welding procedures that must be developed by grouping filler metals that have similar characteristics.*

strength. Overwelding (excess filler metal) not only increases cost, but may also create an undesirable stress concentration at the toe of the weld. See Figure 35-5. Methods of minimizing filler metal quantity include reducing the root opening; using a root face on groove welds; decreasing the groove angle; using single-U grooves; or using double-V or double-U grooves.

Figure 35-5. *Using the appropriate joint design ensures the use of the proper amount of filler metal.*

Effects of Overwelding
Figure 35-5



To calculate the weight of filler metal, multiply the cross-sectional area of the joint by the length of the weld, and multiply the result by the density of the filler metal.

Poor fit-up counteracts the optimizing benefits of the desirable filler metal quantity throughout a joint. Poor fit-up is a common problem with full- or partial-penetration fillet welds in T-joints fabricated in the horizontal position. However, welding in a more difficult position may qualify a less difficult position.

Tack Welding. Tack welding is used to temporarily join parts in proper alignment until the final weld is made. Improperly made or improperly removed tack welds may affect the integrity of the final weld. Tack welding may require the use of designated procedures as indicated in the welding procedure specification. See Figure 35-6.

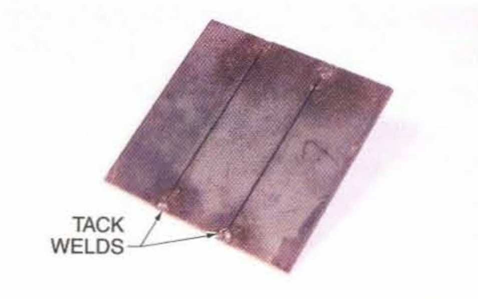


Figure 35-6. *Tack welding must comply with the welding procedure specification if it is incorporated into the final weld.*

Welding Position

Welding position is the relationship of the weld pool, joint, and base metals. Welding positions are flat, horizontal, overhead, and vertical. Welder accessibility must be considered when designing the joint and the assembly pattern to permit a comfortable working environment for the welder.

To achieve the best quality weld, a welder must be able to access the joints from both sides after all areas to be welded have been completely assembled and tack welded. The sequence of assembly may be adjusted to improve welder accessibility. Some welds cannot be accessed from both sides (box columns or small-diameter piping). Such joints are inaccessible and require one-sided welding. See Figure 35-7. When one-sided welding is done, backing material or consumable inserts can be used to ensure complete penetration on the backside of the weld.

When backing material or consumable inserts are not desired or feasible, open root welding must be done. Open root welding requires a higher welding skill than welding with backing and

also requires good fit-up and joint preparation. Care must be taken to achieve the proper root weld without excessive penetration (excessive root reinforcement).

Inaccessible Welds
Figure 35-7

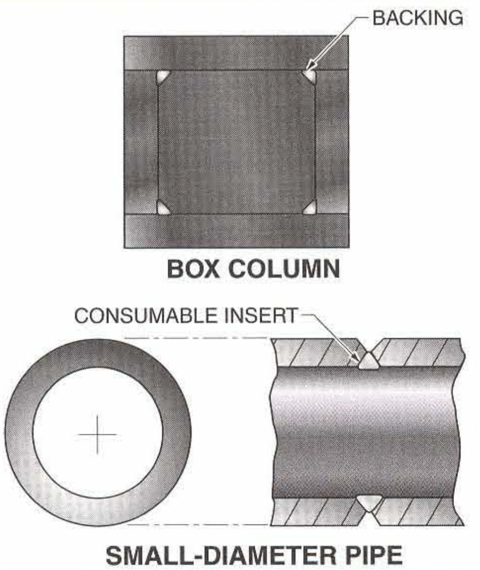


Figure 35-7. *Welder accessibility is a key consideration in creating a sound joint. If a joint is inaccessible, backing material or consumable inserts can be used to ensure complete penetration.*

Preheat, Interpass Temperature Control, and Postheating

Preheat, interpass temperature control, and postheating are welding parameters that indicate the temperature to which the joint must be heated to improve the final properties of the joint. The temperature for each parameter varies depending on the metal to be welded.

Preheat and interpass temperature control are specified when applicable to ensure toughness of the heat-affected zone, particularly for heat-treatable steels. When preheat temperature controls are required, a minimum value must be specified. When interpass temperature control is required, a maximum value must be specified.

Postheating may be specified when welded structures require heat treatment after welding to develop required properties, maintain dimensional stability, reduce residual stress, or further improve toughness. The postheating procedure must be indicated either in the welding procedure specification or on a separate document, such as a shop heat-treating traveler. Postheating procedure requirements include rate of heating and cooling of the structure; time at temperature; and location of weld joint(s) to be postheated.

Shielding Gas

The shielding gas provides a gaseous protective atmosphere that prevents or reduces atmospheric contamination of the molten weld as it solidifies and cools. Shielding gas efficiency relates to the ability of a shielding gas to displace the atmosphere from the arc area. Shielding efficiency depends on shielding gas purity; the design of the nozzle; the distance from the nozzle to the work; the internal diameter or size of the nozzle; the gas flow rate; and side drafts.

Electrical Characteristics

Electrical characteristics should be documented when the welding involves the use of electric current. Electrical characteristics include current type, current level, polarity, and arc voltage. The proper current type and polarity must be defined in the welding procedure.

Welding Technique

The welding technique includes welding procedure details that are controlled by the welder or welding operator. Welding technique parameters include heat input, travel speed, interpass cleaning, and peening.

Heat Input. The heat input influences the weldability or as-welded properties of specific metals. Heat input details must be indicated whenever the heat input could influence the metal properties of the finished weld joint.

Alloys, such as nickel alloys, that are sensitive to hot cracking require heat input controls. When heat input controls are required, details such as using a straight bead or a weave bead must be specified.

A *straight bead* is a type of weld bead made without any appreciable weaving motion. A *weave bead* is a type of weld bead made with transverse oscillation. Using a straight bead or a weave bead can lead to either a reduction or an increase in heat input, respectively. Either bead type may be acceptable for certain types of metals. Many nickel alloys prefer a lower heat input, while chrome-moly steels prefer higher heat input.

Travel Speed. The travel speed used must be consistent throughout the joint to prevent altering the weld properties. Too low a travel speed may cause excessive heat input and impair the properties of a joint. Too fast a travel speed leads to a lack of complete fusion. Documentation of the acceptable travel speed range is always mandatory for automatic welding processes and often mandatory for semiautomatic welding processes.

Interpass Cleaning. Interpass cleaning is required to remove slag from the weld metal and to prepare it for the next pass. Ineffective interpass cleaning may leave slag inclusions in the completed weld and lead to rejection of the weld. Interpass cleaning methods include grinding, chipping, or wire brushing. Interpass cleaning methods are documented for welding processes that leave a slag residue, for example SMAW. See figure 35-8.

Peening. *Peening* is the mechanical working of weld metal using impact blows. Peening reduces the effects of excessive residual stresses and distortion. Peening is used on highly restrained or thick welds to avoid warping or cracking of the weld or base metal. Peening must be performed immediately after completion of a bead length (approximately 9″), as soon as the weld has solidified. Peening is never applied to a root pass or cap pass. Details of peening must be specified to ensure correct application of the method.

Figure 35-8. *Interpass cleaning is required to remove slag from the weld and prevent slag inclusions.*

Oxyfuel Welding Qualification Variables

Oxyfuel welding qualification variables are similar to those for arc welding, where applicable. Unique qualification variables for oxyfuel welding are fuel gas requirements and welding tip size.

Fuel Gas Requirements. Fuel gas requirements that must be specified are fuel gas composition and gas pressure. The fuel gas composition is the combination of fuel gases that is to be used with oxygen to perform the welding. Acetylene is an example of a fuel gas. Oxygen is always used to support combustion in oxyfuel welding, so the pressure required at the regulators of both the fuel gas and the oxygen is indicated. The corresponding flame type (oxidizing, reducing, or neutral) must also be indicated.

Welding Tip Size. The welding tip size is the size of the orifice in the oxyfuel welding torch. The orifice is the point from which the oxyfuel welding gases issue. The size of the welding tip controls gas consumption during welding and must be documented on the PQR.

Brazing Qualification Variables

Brazing qualification variables are the same as for arc welding, where applicable. Qualification variables unique to brazing are brazing temperature range; brazing flux; brazing joint design and clearance; brazing position; and brazing time. Brazing variables are indicated on a Brazing Procedure Specification. See Figure 35-9.

Brazing Temperature Ranges. *Brazing temperature range* is the temperature range within which the base metal is heated to enable filler metal to wet the base metal and form a brazed joint. The temperature range must melt the filler metal at a temperature below the melting point of the base metal(s). Filler metals for brazing are those that melt at temperatures above 840°F (450°C).

Brazing Procedure Specification
Figure 35-9

BRAZING PROCEDURE SPECIFICATION (BPS)

BPS No. ______ Date ______ B PQR NO. ______

Company ______

Brazing Process ______ Manual ☐ Mechanized ☐ Automatic ☐

Brazing Equipment ______

BRAZING CONDITIONS

BASE METAL:

Identification ______ BM No. ______

Thickness ______ Preparation ______

Other ______

FILLER METAL:

FM No. ______ AWS Classification ______

Form ______ Method of Application ______

FLUX: AWS Type ______ Other ______

ATMOSPHERE: AWS Type ______ Other ______

TEMPERATURE: ______ TEST POSITION: ______

TIME: ______ CURRENT: ______

FUEL GAS: ______ TIP SIZE: ______

POSTBRAZE CLEANING: ______

POSTBRAZE HEAT TREATMENT: ______

OTHER: ______

JOINT:

Type ______

Clearance ______

UTS ______

Other ______

______

Approved for production by ______ Employer

JOINT SKETCH

Figure 35-9. *Brazing qualification variables are documented on a brazing procedure specification form.*

Brazing Flux. Brazing flux is intended to prevent or inhibit the formation of oxides during brazing. Brazing atmospheres include combusted fuel gas, hydrogen, or vacuum. Brazing flux constituents include borax, chloride, fluorides, or any combination of these with other chemicals. The chemicals within the flux are the agents that prevent or remove the oxides or other undesirable substances during brazing.

Brazing Joint Designs and Clearances. The two basic joints used for brazing are the lap joint and the butt joint. The lap joint is the most commonly used because it offers a large surface area for the greatest strength. Joint design is also based on joint clearance. Joint clearance has a major effect on the mechanical properties of a brazed joint. Adequate joint clearance should fall in the range between .001″ and .010″. Recommended joint clearances vary with the type of filler metal and the thickness of the base metal. Brazing joint design and clearance influence the strength of a brazed joint. Changes to joint design and clearance outside of tabulated values require requalification.

Brazing Positions. The brazing position, if altered, requires requalification, with certain exceptions. Basic brazing positions for plate are flat, vertical downflow, vertical upflow, and horizontal. Basic brazing positions for pipe are horizontal, vertical downflow, and vertical upflow. See Figure 35-10. In the vertical downflow and vertical upflow positions, the joint faces are vertical and capillary flow of the filler metal is up and down, respectively. In the horizontal position for plate or pipe, the joint faces are also vertical, but the capillary flow of the filler metal is horizontal.

Brazing Time. The brazing time requirement must be requalified if it exceeds or fails to meet the brazing time indicated for the qualification test by a prescribed percentage.

Surfacing Weld Qualification Variables

Qualification variables for surfacing welds are the same as those for arc welding, where applicable. The qualification variable unique to surfacing welds is the chemical composition of the surfacing weld.

Chemical Composition of Surfacing Welds. The chemical composition of a surfacing weld influences wear resistance for hard facing and corrosion resistance for corrosion-resistant overlays. The chemical composition of a surfacing weld can be altered by

QUALIFIED BRAZING POSITIONS								
Test Brazement Form	Test Brazing Position	Plate				Pipe		
		Flat Flow	Vertical Downflow	Vertical Upflow	Horizontal Flow	Horizontal Flow	Vertical Downflow	Vertical Upflow
Plate	Flat Flow	X	X	—	—	—	—	—
	Vertical Downflow	—	X	—	—	—	—	—
	Vertical Upflow	—	X	X	—	—	—	—
	Horizontal Flow	—	X	—	X	—	—	—
Pipe	Horizontal Flow	X	X	—	X	X	X	—
	Vertical Downflow	—	X	—	—	—	X	—
	Vertical Upflow	—	X	X	—	—	X	X

Figure 35-10. *The position of the test brazement may qualify one or more brazing positions.*

dilution with the base metal. Different welding processes create different amounts of dilution. To overcome dilution, additional surfacing weld passes or modification of the welding procedure may be required. The chemical composition of the surfacing weld must be maintained on the surface layers, without excessive dilution. The measured chemical composition of the surfacing deposit must be within a prescribed percentage of the actual chemical composition of the base metal. It may be necessary to reduce heat input to reduce dilution.

Resistance Welding Qualification Variables

Resistance welding (RW) qualification variables are the same as those for arc welding, where applicable. Resistance welding qualification variables unique to RW are joint design; electrode type and size; weld size and strength; and surface appearance.

The joint design must account for contacting overlap, weld spacing, and the type and size of projection. Electrode variables include the alloy used, the contour, and the dimensions. If plates, dies, blocks, or other such devices are used whose properties would affect the quality of the welding, they should be specified. Weld size and strength must describe the extent of the joint and the anticipated strength value to be obtained by mechanical testing.

Surface appearance includes factors such as indentation, discoloration, or amount of upset. A general requirement for surface appearance may be sufficient. A statement such as "Surface shall be generally free of discoloration or indentations" is acceptable.

WELDING PROCEDURE SPECIFICATION (WPS)

A *welding procedure specification (WPS)* is a document providing the required welding variables for a specific application to ensure repeatability by properly trained welders and welding operators. The WPS provides formal documentation for all welding qualification variables. The WPS is the "recipe" that must be followed when making the weld.

Information regarding test specifications and procedures are detailed in ANSI/AWS B2.1, *Welding Procedure and Performance Qualification.* As part of the procedure for qualification, forms are completed that specify all welding directives and requirements (Welding Procedure Specifications). See Appendix.

Fabrication standards and codes require an employer to prepare and qualify welding procedure specifications relevant to all fabrication work. The standards and codes define the details to be included in a WPS and refer only to the welding variables of the specific process that affect qualification. The user is allowed to determine what other variables and information should be included in the WPS.

Welding procedure specification items include WPS details, WPS variables, WPS conformance, WPS development, and standard WPSs.

WPS Details

WPS details describe all the welding qualification variables required by the applicable fabrication standard or code. The WPS details may be brief or long and detailed. Fabrication standards and codes usually contain suggested WPS forms on which to document qualification variables and other relevant information. For complex welded structures, the suggested WPS forms must be supplemented with additional notes or instructions, or new WPS forms are devised to suit specific requirements. See Appendix.

A WPS provides direction to the welder or welding operator and is an important control document. The WPS

A WPS includes essential, supplementary essential, and nonessential variables.

is given a specific reference number and must be signed by an authorized person, such as the fabricator's quality assurance manager, before release for production welding. Responsibility for the content, qualification status, and use of a WPS rests with the employer.

WPS Variables

WPS variables are qualification variables that require documentation in a WPS. WPS variables are essential variables, supplementary essential variables, and nonessential variables.

Essential variables are parameters which, if changed, could alter the mechanical properties of the weld. Requalification of the new variables is required.

Essential Variables. An *essential variable* is a welding qualification variable which, if altered, shall be considered to affect the mechanical properties of the weld. If an essential variable is altered in a welding procedure, the welding procedure is considered to be revised and the new procedure must be requalified. Essential variables are indicated in fabrication standards and codes. Essential variables differ depending on the welding process and the fabrication standards and codes. See Figure 35-11.

Supplementary essential variables are parameters which affect the impact properties (toughness) of the weld. Requalification of the new variables is required.

Supplementary Essential Variables. A *supplementary essential variable* is a qualification variable, for metals where impact testing is required, that requires a new welding procedure specification. The supplementary essential variable is a provision of some fabrication standards and codes, such as the ASME Boiler and Pressure Vessel Code.

Nonessential variables are parameters which, if changed, do not alter the mechanical properties of the weld and do not require requalification of the weld.

Nonessential Variables. A *nonessential variable* is a qualification variable that may be changed in a WPS without requalification of the WPS. Nonessential variables differ for different welding processes and for different fabrication standards and codes.

WPS Conformance

Conformance with the WPS is required to meet the applicable fabrication standard or code. Many fabrication standards or codes reference the ASME Boiler and Pressure Vessel Code, Section IX, *Qualification Standard for Welding and Brazing Procedures — Welders, Brazers, and Welding and Brazing Operators.*

All fabrication codes and standards indicate a specific level of conformance to welding performance or procedure qualification that must be met. Section IX of the ASME Boiler and Pressure Vessel Code requires the manufacturer or contractor to take responsibility for performing qualification testing of welding procedures for the weldments to be built under the code and for the performance of the welders who will carry out the welding. Section IX also requires the manufacturer or contractor to maintain an accurate, certified record of the results obtained during welding, as well as during procedure and performance qualification tests. Records must be available to authorized inspectors.

WPS Development

WPS development is generally the responsibility of the contractor in a given production shop. The end user or their representative specifies the properties desired in weldments in accordance with a code, specification, or special design requirements. The contractor then develops a welding procedure that will produce the specified results, if a relevant procedure does not already exist. Certain fabrication codes and standards require welding procedure qualification, which is a prequalification test for welding and is an exception to the general requirements for WPS development.

The AWS publishes standard AWS B2, Specification for Welding Procedure and Performance Qualification, *to help welders understand and meet the procedure qualification requirements of a WPS.*

VARIABLE CHANGES THAT REQUIRE REQUALIFICATION. . .		
Procedure Variable*	**Procedure Requalification Required**	**Welder/Welding Operator Requalification Required**
Type, composition, or process condition of the base metal	• When the base metal is changed to one that does not conform to the type, specification, or process condition qualified • Some codes and specifications provide lists of materials that may be substituted without requalification	• Usually not required
Thickness of base metal	• When the thickness to be welded is outside the qualified range • Most codes provide for qualification on one thickness within a reasonable range • Some codes may require qualification on exact thickness or on min and max. thicknesses	• When the thickness to be welded is outside the qualified range • Most codes provide for an unlimited thickness test
Joint design	• When established limits of root openings, root face, and included angle of groove joints are increased or decreased • Some codes and specifications define upper and lower limits beyond which requalification is necessary. Others permit an increase in groove angle and root opening and a decrease in the root face without requalification • Requalification is often required when a backing or spacer strip is added or removed, or the basic type of material of backing or spacer strip is changed	• When changing from a double-welded joint or a joint using backing material to an open root, and vice versa • The addition or deletion of a consumable insert
Pipe diameter	• Usually not required • Some codes permit procedure qualification on plate to satisfy the requirements for welding on pipe	• When the diameter of piping or tubing is reduced below specified limits. • Smaller pipe diameters generally require more sophisticated techniques, equipment, and skills
Type of current or polarity (if DC)	• Usually not required for changes involving electrodes or welding materials adapted for the changed electrical characteristics • Sometimes required for change from AC to DC, or vice versa, or from one polarity to the other	• Usually not required for changes involving similar electrodes or welding materials adapted for the changed electrical characteristics
Electrode classification and size	• When electrode classification is changed • When the diameter is increased beyond allowable ranges specified in the relevant code	• When electrode classification grouping is changed • Sometimes when the electrode diameter is increased beyond specified limits
Welding current	• When the current is outside the range qualified	• Usually not required
Position or progression or both	• Usually not required, but desirable	• When the change exceeds the limits of the position(s) qualified or a change in progression
Deposition of filler metal	• When a marked change is made in the manner of filler metal deposition; e.g., from a small bead to large bead or weave arrangement or from an annealing pass to a no-annealing-pass arrangement, or vice versa	• Usually not required

* General requirements for requalification of welding procedures and welder performance. Not for use by inspector to determine necessity of requalification. Inspectors must reference the applicable code or standard for the work being inspected.

Figure 35-11...

. . . VARIABLE CHANGES THAT REQUIRE REQUALIFICATION		
Procedure Variable*	**Procedure Requalification Required**	**Welder/Welding Operator Requalification Required**
Preparation of root for second side welding	• When method or extent is changed	• Usually not required
Preheat and interpass temperatures	• When preheat or interpass temperature is outside the qualified range	• Usually not required
Postheating	• When adding or deleting postheating • When the postheating temperature or time cycle is outside the qualified range	• Usually not required

* General requirements for requalification of welding procedures and welder performance. Not for use by inspector to determine necessity of requalification. Inspectors must reference the applicable code or standard for the work being inspected.

...Figure 35-11. *Essential welding variables require requalification if they are changed.*

PROCEDURE QUALIFICATION RECORD (PQR)

A *procedure qualification record (PQR)* is documentation of the welding variables used to produce an acceptable test weld and the test results conducted on the weld to qualify a WPS. A procedure qualification record determines, by preparation and testing of standards specimens, whether welding in accordance with a WPS will produce sound welds and adequate joint properties. The test results are documented in a procedure qualification record (PQR).

A procedure qualification record (PQR) is documentation of the welding variables used to produce an acceptable test weld and the test results conducted on the weld to qualify a WPS.

To support a WPS, it is necessary to test and certify the results in a PQR. This is done by making the welds described in the WPS, machining them into test samples, and testing the samples in accordance with the applicable fabrication code and standard.

PQR Details

Much of the data required by the PQR is the same as the information referenced in the WPS. All essential variables and, when applicable, supplemental essential variables, must be included. Nonessential variables are optional, but when included must be accurate. The data on the front sheet of the PQR and the WPS will often look very similar. A PQR records exact data of what actually took place during the test. A WPS lists a range of allowable variables. The back of the PQR is a record of the mechanical test results. Mechanical tests that may be used include the tensile test, guided bend test, toughness test (when required), and fillet weld test (when required). See Appendix.

PQR development encompasses welding a sample joint within the applicable parameters of the WPS, testing the joint, and recording the results.

A change in any variable beyond the allowable limits of the applicable fabrication standard or code requires requalification of the WPS with a new PQR. Any change within allowable limits requires only documentation in a revised WPS.

The applicable fabrication code or standard provides general guidance and specific acceptance-rejection criteria for evaluating test results. Minimum tensile strength, maximum number of inclusions, or the permissible level of other discontinuities may be specified. The acceptability of properties or conditions is based on engineering judgment and is especially important for service at high or low temperature, or in corrosive environments. PQRs vary for the type of welding process. In some cases the type of fabrication may require mock-up tests or may allow the use of a prequalified WPS.

PQR Steps

The steps involved in PQR are welding a sample joint within the parameters of the WPS qualification variables; testing the sample joint using standardized protocols; and recording the test results in the PQR.

Welding a Sample Joint. Welding a sample joint is usually done using pipe or plate samples, with a welding joint made to the qualification variables indicated in the WPS. The type, size, and thickness of the test sample are governed by the type, size, and thickness of the base metal to be welded in production, and by the nature of the pieces to be removed for test specimen preparation. Test specimen requirements are usually indicated in the applicable fabrication standard or code.

Testing a Sample Joint. Sample joint testing is performed on test specimens that have been removed from the sample weld joint. The type and number of test specimens depends on the requirements of the applicable fabrication standard or code. In most cases, the test specimens used are for tensile testing and guided bend testing. Exact testing requirements are indicated in the applicable fabrication standard or code.

Test specimens made from fillet welds are usually subjected to tensile-shear testing and macroetching. Testing determines the strength, ductility, soundness, and adequacy of fusion of the welds.

Nondestructive examination (NDE) of the sample joints is usually preferred before they are sectioned for test specimen preparation. Specific NDE procedures may be a requirement of the applicable fabrication standard or code.

If a fabricator has qualified a welding procedure, and at some later date wishes to make modifications in that procedure, it may be necessary to conduct requalification tests.

Requalification tests establish that the modified welding procedure will produce satisfactory results. Requalification tests are not usually required when only minor details of the original procedure are changed. They are required, however, if the changes might alter the properties of the resulting welds. The applicable fabrication standard or code provides guidance on whether requalification tests are required.

Recording Test Results. Recording test results in the PQR is done when the qualifier is satisfied that the results are accurate. The PQR is signed to certify the test results. If the test results meet the requirements of a job specification, the supported WPS may be issued for production welding.

A PQR is a certified record of a qualification test and should not be revised. If information needs to be added later, it can be added in the form of a supplement or attachment. Additional qualification tests may be required if an employer later wishes to make changes to a WPS. A PQR may support several WPSs, and a WPS may be supported by several PQRs.

Several PQRs can support a single WPS, and several WPSs can be supported by a single PQR.

If changes become necessary in an established and qualified WPS, additional qualification tests may be needed to determine whether the modified WPS will yield satisfactory results. The applicable fabrication standard or code determines if requalification is needed.

Alternate PQR Documentation

Alternate PQR documentation encompasses various methods of qualifying welding procedures. Alternate PQR documentation includes prequalified WPS, mock-up tests, brazing PQR, and resistance welding PQR.

A prequalified WPS is a WPS that complies with a specific fabrication code or standard and requires no qualification testing.

Prequalified PQR. A *prequalified WPS* is a welding procedure specification that complies with the stipulated conditions of a particular fabrication standard or code and is acceptable for use under that code without requiring additional qualification testing. Prequalified welding procedures may be used as an alternate to testing by each employer.

In order to use a prequalified WPS the employer prepares a written WPS conforming to the specific requirements

of the applicable fabrication standard or code for the welding variables defined. The written WPS is a record of materials and welding procedure qualification variables that demonstrates that the joint welding procedure meets the requirements for prequalified status. For AWS D1.1, *Structural Welding Code — Steel,* this work is done under the requirements of AWS D1.1.

Welding procedure qualification tests need not be made if the requirements are followed in detail. The employer must accept responsibility for the use of prequalified WPSs. The use of prequalified welding procedures does not guarantee satisfactory production welds. The quality of all production welds should be verified by NDE during and after welding.

Mock-up tests are used to simulate actual welding jobs under difficult or restricted conditions, such as for heat exchanger tube-tubesheet joints.

A standard WPS is a type of prequalified WPS. A standard WPS is one developed through analysis of thousands of qualified welding procedures that provide restricted ranges of welding variables to ensure a high probability of successful application by end users. Standard WPSs are approved for some fabrication codes, such as for sheet metal.

Mock-up Tests. Mock-up tests are used to simulate actual production welding conditions in certain types of fabrication jobs, usually under difficult or restricted welding conditions. Mock-up tests verify that proper tooling and inspection have been selected.

Certain variables such as joint geometry, welding position, and accessibility may not be considered as qualification variables. Often, the only way to gauge their effect is with mock-ups. Fabrication standards and codes do not usually require the fabrication of mock-ups for destructive examination unless they are to demonstrate that the welding procedures will produce the specified welds. For example, although mock-up tests are used to verify welding procedures for heat exchanger tube-tubesheet joints, the mock-up tests must be supported by a qualified WPS. Mock-up tests are a useful method of demonstrating expected quality levels under difficult or restricted welding conditions. See Figure 35-12.

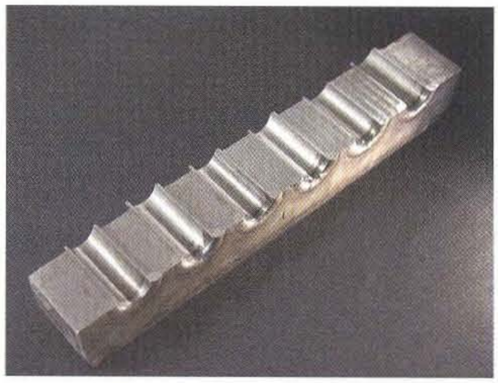


Figure 35-12. *A mock-up is used for a mock-up test to simulate actual production welding situations to ensure proper tooling and techniques are selected, such as for heat exchanger tube-tubesheet joints.*

Brazing PQR. Brazing procedure qualification testing consists of various destructive tests on test specimens obtained from braze samples made to the applicable brazing procedure specification. Test results are recorded on the Brazing Procedure Qualification Record and certified by the witnessing contractor representative.

Resistance Welding PQR. Resistance welding procedure qualification tests vary and depend largely on the type of work to be produced. When the welded part is small, the procedure may be qualified by making a number of finished pieces and testing them to destruction under service conditions, either simulated or real. In other cases, resistance welds can be made in test specimens that are tested in tension or shear, or inspected for other properties such as surface appearance and soundness.

A procedure qualification record determines, by preparation and testing of standards specimens, whether welding in accordance with a WPS will produce sound welds and adequate joint properties. Much of the data required by the PQR is the same as the information referenced in the WPS.

POINTS TO REMEMBER

1. Qualified welding procedures consist of the welding procedure specification (WPS) and the procedure qualification record (PQR).
2. Welding procedure qualification variables are welding parameters that affect the integrity of a weld joint and must be indicated in the PQR.
3. Joint design is an example of a procedure qualification variable and may encompass weld type, edge preparation, and method of preparing the edge.
4. Base metals are grouped by weldability classifications to reduce the number of procedure qualification variables. Base metals with the same weldability classification may be substituted for one another with no effect.
5. Filler metals are grouped by usability classification to reduce the number of procedure qualification variables. Filler metals with the same usability classification may be substituted for one another with no effect.
6. A WPS includes essential, supplementary essential, and nonessential variables.
7. Essential variables are parameters which, if changed, could alter the mechanical properties of the weld. Requalification of the new variables is required.
8. Supplementary essential variables are parameters which affect the impact properties (toughness) of the weld. Requalification of the new variables is required.
9. Nonessential variables are parameters which, if changed, do not alter the mechanical properties of the weld and do not require requalification of the weld.
10. A procedure qualification record (PQR) is documentation of the welding variables used to produce an acceptable test weld and the test results conducted on the weld to qualify a WPS.
11. PQR development encompasses welding a sample joint within the applicable parameters of the WPS, testing the joint, and recording the results.
12. Several PQRs can support a single WPS, and several WPSs can be supported by a single PQR.
13. A prequalified WPS is a WPS that complies with a specific fabrication code or standard and requires no qualification testing.
14. Mock-up tests are used to simulate actual welding jobs under difficult or restricted conditions, such as for heat exchanger tube-tubesheet joints.

QUESTIONS FOR STUDY AND DISCUSSION

1. What is one benefit of using an effective joint design?
2. What is the difference between base metal material specification and base metal weldability classification?
3. What is the range of base metal thicknesses covered in a welding procedure specification?
4. What is the difference between filler metal specification and filler metal usability classification?
5. Why are small-diameter electrodes preferable to large-diameter electrodes?
6. What is one benefit of postheating?
7. Why does a straight bead provide less heat input to a weld than a weave bead?
8. What are the effects of travel speeds that are too slow? Travel speeds that are too fast?
9. What is the effect of ineffective interpass cleaning?
10. What WPS variables require documentation in the WPS?
11. What are the three steps required in creating a PQR?
12. How is a mock-up test useful when supported by a qualified WPS?

Welder Performance Qualification 36

Weld Evaluation and Testing

The welder performance qualification (WPQ) test demonstrates a welder's ability to produce welds that meet a qualified welding procedure. Welder performance qualification tests are used to assess whether a welder has the required level of skill to produce a sound weld to the parameters of the applicable welding procedure specification (WPS).

The employer is responsible for ensuring that welder performance qualification tests meet the requirements of the applicable fabrication standard or code. Fabrication standards and codes contain similar methods of qualifying welders, welding operators, and tack welders, but differ in the requirement details. Welder performance qualification (WPQ) tests must be made in the most difficult position encountered in production. However, WPQ test results cannot predict how an individual will perform on a particular production weld. The quality of production welds should be determined by inspection both during and following completion of welding.

WELDER PERFORMANCE QUALIFICATION (WPQ)

A welder performance qualification (WPQ) contains three areas that must be certified for a welder to be approved for qualification: welder performance qualification, welder certification, and welder registration. The *welder performance qualification* is a test that demonstrates a welder's ability to produce welds that meet required standards. The welder performance qualification involves taking and passing a practical welding test.

Welder certification is a written statement that the welder has produced welds meeting a prescribed standard of welding performance. Welder certification implies that a testing organization, a manufacturer, a contractor, an owner, or a user has witnessed the preparation of the test welds, has conducted the prescribed testing of the welds, and has recorded the successful results of a test in accordance with accepted standards. *Welder registration* is the act of approving a copy of the welder's certification document by an appropriate authority.

A welder performance qualification (WPQ) demonstrates a welder's ability to produce welds to meet the applicable welding procedure specification (WPS).

WPQ STANDARDS AND CODES

Many fabrication standards and codes exist, each having its own regulatory requirements. WPQ requirements vary between standards and codes, and the appropriate fabrication code or standard must be used when qualifying welders, welding operators, and tack welders.

AWS D1.1, Structural Welding Code—Steel, *is an example of a standard that contains qualification requirements for welders, welding operators, and tack welders. Performance qualification requirements are found in Section 4, Qualification, Part C, Performance Qualification.*

Qualification under one fabrication code or standard does not necessarily qualify a welder to weld under another code or standard, even though the qualification tests appear to be identical.

The governing standard or code should be consulted for specific details. Requirements for the ASME Boiler and Pressure Vessel Code, AWS *Structural Welding Code—Steel,* AWS *Structural Welding Code—Sheet Steel,* and API *Cross Country Pipeline Welding* are typically specified. Qualification under one fabrication code or standard does not necessarily qualify a welder to weld under another code or standard, even though the qualification tests appear to be identical.

ASME Boiler and Pressure Vessel Code

Structural welding code WPQ requirements are contained in AWS D1.1, Structural Welding Code—Steel.

Boiler and pressure vessel code requirements are contained in ASME Section IX, *Qualification Standard for Welding and Brazing Procedures—Welders, Brazers, and Welding and Brazing Operators.* Section IX requirements also apply to other structures such as elevated water storage tanks and oil storage tanks.

Per ASME requirements, the welder who prepares test samples for the WPQ must be personally qualified within ASME performance qualification variables. All other welders are qualified by specific welder qualification tests required by the welding procedure specification (WPS) that will cover the work. A welding procedure qualification record (PQR) is used to document the ability of the welder or welding operator to meet the WPS.

A PQR must include the essential welding variables, the range qualified, the type of test, and the test results.

A PQR must include the essential welding variables, the type of test, the metal thickness ranges qualified, and the test results. When testing, RT may sometimes be substituted for mechanical tests, but not when GMAW with short circuiting transfer is used. RT cannot be used because incomplete fusion, a common discontinuity with GMAW in the short circuiting mode, may not be detected by RT. See Appendix.

Generally, welders who meet the requirements for groove welds are also qualified for fillet welds, but not vice versa. A welder qualified to weld in accordance with one qualified WPS is also qualified to weld in accordance with other qualified WPSs using the same welding process, within the limits of the indicated essential welding variables.

A qualified welder is given an identifying number, letter, or symbol that is used to identify his or her work. The qualification expires if the welder does not weld for a period of six months or more. Moreover, if there is reason to question the welder's ability to make welds meeting specifications, his or her qualification shall be considered expired.

AWS Structural Welding Code—Steel

Structural welding code WPQ requirements are contained in AWS D1.1, *Structural Welding Code—Steel.* AWS requirements are similar to those of the ASME Boiler and Pressure Vessel Code, but also contain provisions for prequalified welding procedures.

Under the AWS code, visual inspection, guided bend tests, fillet weld tests, and RT may be used to test sample welds. The *Structural Welding Code—Steel* also allows, at the engineer's discretion, acceptance of proper documented evidence of previous qualifications of welders.

AWS Structural Welding Code—Sheet Steel

The structural welding code for sheet steel welder qualifications is contained in AWS D1.2, *Structural Welding Code—Sheet Steel.* The requirements are different from AWS D1.1 for structural steel in that qualification, when established for any one of the steels permitted by the code, allows the welder to be qualified to weld on any other steel permitted by the code, except for coated steels. Qualification on coated steels must be tested on coated steels.

Qualification is required in each position used. In the case of vertical position, uphill or downhill travel is qualified. Welders are qualified for all electrodes within a group designation (usability classification). Different combinations of electrode and shielding gas must be qualified separately. If any of the procedure qualification variables are changed, the procedure must be requalified under the new variables. See Figure 36-1. Check with the fabrication code and specification for actual essential variables.

ESSENTIAL WELDING VARIABLES*
Electrode/Filler Metal
• Electrode classification • Electrode size • Increase in filler metal strength • Melting rate/current/wire feed speed • Type of coating • Coating thickness • Use of flux (for SAW)
Position
• Change in position • For vertical welding: uphill vs. downhill; downhill vs. uphill • Welding from both sides to welding from one side only (for square butt joints)
Shielding Gas
• Type of shielding gas (for GMAW and GTAW) • Flow rate (for GMAW and GTAW)
Current
• Current level/wire feed speed/melting rate • Type of welding current, polarity
Base Metal
• Sheet steel thickness
Joint Design
• Root opening of square butt joints
Welding Process
• Mode of metal transfer (for GMAW)†

* require requalification if changed
† only essential when switching from short circuiting to spray transfer

Figure 36-1. *Essential welding variables are qualified as tested. Welders must be requalified when essential welding variables are changed.*

Cross-Country Pipeline Welding Code

Cross-country pipeline welder qualification requirements are contained in API standard 1104, *Standard for Welding Pipelines and Related Facilities.* The requirements are different from the previously described codes in that cross-country pipeline welder qualification and testing is usually done in the field. See Figure 36-2.

API allows for the use of tensile tests, bend tests, and nick-break tests. Welders can be qualified for a single qualification or multiple qualifications, depending on the results of each test attempted.

PRODUCT-SPECIFIC WPQs

Product-specific welder performance qualification tests are most commonly done for plate and structural member welding, pipe welding, sheet metal welding, and brazing.

Welder performance qualifications test the most difficult positions that will be encountered in production for welding and brazing. Qualification in a more difficult position usually also qualifies for welding or brazing in less difficult positions. A welder who qualifies in vertical, horizontal, or overhead positions is usually also considered qualified for welding or brazing in flat position. Qualification on a groove weld test will normally qualify that welder for the production of fillet welds in the same position. The applicable fabrication standard or code dictates the exact limits on production welding and brazing qualification test positions.

The WPQ must be developed for the most difficult position expected during welding or brazing.

AWS D1.1, Structural Welding Code—Steel, *Table 4.10, Welder and Welding Operator Qualification: Number and Type of Specimens and Range of Thickness and Diameter Qualified, specifies the type of test welds, metal thickness, number of specimens, and the qualified dimensions for production welding.*

Reference: API Standard 1104, 2.2

PROCEDURE SPECIFICATION NO. ____________

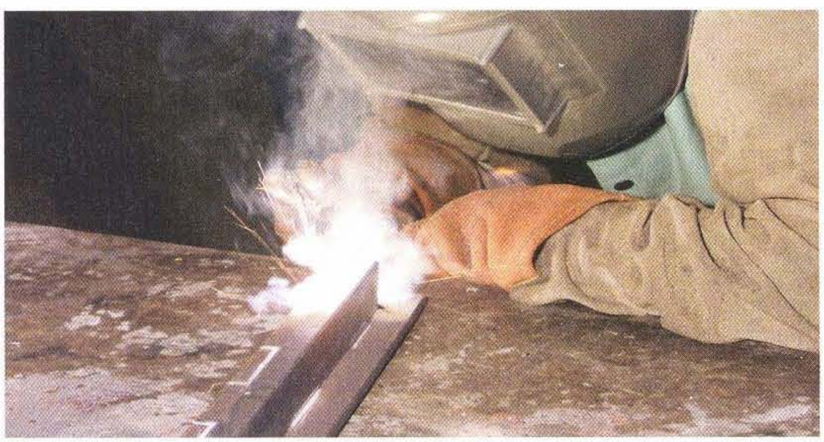
For ______________________ Welding of ______________________ Pipe and Fittings
Process ______________________
Material ______________________
Diameter and wall thickness ______________________
Joint design ______________________
Filler metal and No. of beads ______________________
Electrical or flame characteristics ______________________
Position ______________________
Direction of welding ______________________
No. of welders ______________________
Time lapse between passes ______________________
Type and removal of lineup clamp ______________________
Cleaning and/or grinding ______________________
Preheat/stress relief ______________________
Shielded gas and flow rate ______________________
Shielding flux ______________________
Speed of travel ______________________
Sketches and tabulations attached ______________________

Tested ______________________ Welder ______________________
Approved ______________________ Welding supervisor ______________________
Adopted ______________________ Chief engineer ______________________

ELECTRODE SIZE AND NUMBER OF BEADS

Bead Number	Electrode Size and Type	Voltage	Current and Polarity	Speed

Figure 36-2. *WPQ tests to meet API 1104 are usually performed in the field.*



A welder performance qualification test qualifies a welder based on the essential variables specified on the welding performance qualification record.

WPQ for Plate and Structural Members

Welder performance qualification for plate and structural members usually requires that the welder make one or more test welds on groove weld plate or fillet weld plate in accordance with the requirements of the qualified WPS. The welder would then be qualified to weld plates up to 2T (where T is the thickness of the qualification plate). Joint details should be in accordance with the qualified PQR.

Groove weld qualifications usually qualify the welder to weld both fillet welds and groove welds in the positions qualified. Fillet weld qualifications limit the welder to fillet welding in only the position qualified and other specified positions of less difficulty. WPQ samples for groove and fillet welds are taken from key locations in the test joint.

WPQ for Pipe

Welder performance qualifications for pipe differ from plate and structural member welding principally in the test assemblies and the test positions used. When welding pipe, the root surface is inaccessible, requiring the use of backing rings or consumable inserts, or the production of a weld with an open root joint. An *open root joint* is an unwelded joint that does not use backing or consumable inserts.

Pipe welding requires more skill than welding plate or structural members with backing. To simulate the difficulties of production pipe welding, the WPQ for pipe requires that pipe samples be welded in the position, or positions, for which the welder is to be qualified. Space restrictions may also be placed on the welder during the test. Space restrictions measure the individual's ability to produce a satisfactory weld in locations where joint access is limited. Special joint designs are used for welder performance qualification to weld T-, K-, or Y-connections in pipe and for fillet or tack welds.

WPQ for Sheet Steel

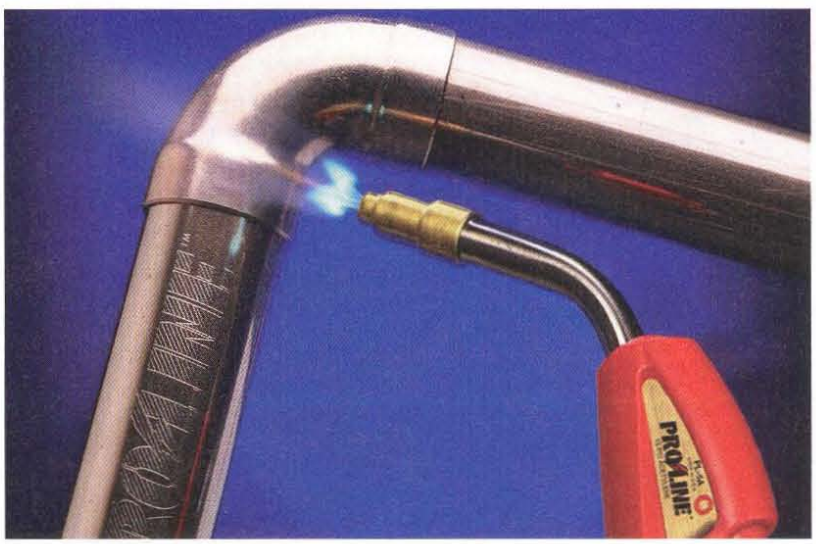
Welder performance qualifications for sheet steel are based upon special requirements for joining thin members. Welding thin metals could result in holes burning through the sections. All fabrication standards and codes place limits on the minimum thickness that a welder can weld in production. The minimum thickness qualified is often the thickness used during qualification. See Figure 36-3.

WPQ for Brazing

Welder performance qualification for brazing is based upon the production of a joint arrangement in a similar position to that expected in production. Brazing operators are tested to verify their ability to operate mechanized or automatic brazing equipment according to a brazing procedure specification.

Acceptance of welder performance qualification tests on brazed joints may be based either on visual examination or on specimen testing. Welder performance qualification for brazing by specimen testing is done by making a standard test brazed joint consisting of a butt, scarf, lap, single- or double-spliced butt, or a rabbet joint in plate or pipe. See Figure 36-4.

The test pipe is sectioned and the exposed surfaces are polished and etched, and a macroetch test is done. A macroetch test is a way to examine a brazed joint at low magnification for discontinuities. Peel tests may be used in place of macroetch tests, or vice versa, using lap joints or spliced butt joints.



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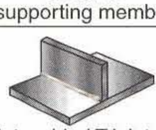
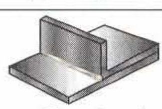
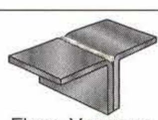
A WPQ for brazing requires that a joint be made in a position similar to that required in production. Brazing operators must be able to operate machinery or brazing equipment according to the brazing procedure specification.

WELDER PERFORMANCE QUALIFICATION TESTS FOR SHEET STEEL					
Test Samples	**Tested Welding Position**	**Qualified Welding Position**	**Qualified Weld Joint**	**Thickness**	**Type of Test***
 Square groove butt joint, sheet to sheet	Flat Horizontal Vertical Overhead	Flat Flat, Horizontal Flat, Horizontal, Vertical Flat, Horizontal, Overhead	Square groove butt joint, sheet to sheet	Thickness tested	Bend
 Arc spot weld, sheet to supporting member	Flat	Flat	Arc spot weld and arc seam weld, sheet to supporting member	Thickness tested	Twist
 Arc seam weld, sheet to supporting member	Flat	Flat	Arc seam weld, sheet to supporting member	Thickness tested	Bend
 Arc seam weld, sheet to sheet	Horizontal	Horizontal	Arc seam weld, sheet to sheet	Thickness tested	Bend
 Fillet welded lap joint, sheet to sheet	Flat Horizontal Vertical Overhead	Flat Flat, Horizontal Flat, Horizontal, Vertical Flat, Horizontal, Overhead	Fillet welded lap joint, sheet to sheet, or sheet to supporting member	Thickness tested and thicker	Bend
 Fillet welded lap joint, sheet to supporting member	Flat Horizontal Vertical Overhead	Flat Flat, Horizontal Flat, Horizontal, Vertical Flat, Horizontal, Overhead	Fillet welded lap joint, sheet to sheet, or sheet to supporting member	Thickness tested and thicker	Bend
 Fillet welded T-joint, sheet to sheet	Flat Horizontal Vertical Overhead	Flat Flat, Horizontal Flat, Horizontal, Vertical Flat, Horizontal, Overhead	Fillet welded T- or lap joint, sheet to sheet, or sheet to supporting member	Thickness tested and thicker	Bend
 Fillet welded T-joint, sheet to supporting member	Flat Horizontal Overhead	Flat Flat, Horizontal Flat, Horizontal, Overhead	Fillet welded T- or lap joint, sheet to supporting member	Thickness tested and thicker	Bend
 Flare-bevel, sheet to sheet	Flat Horizontal Vertical Overhead	Flat Flat, Horizontal Flat, Horizontal, Vertical Flat, Horizontal, Overhead	Flare-bevel-groove weld, sheet to sheet, or sheet to supporting member; or Flare-V-groove weld, sheet to sheet	Thickness tested and thicker	Bend
 Flare-bevel-groove, sheet to supporting member	Flat Horizontal Vertical	Flat Flat, Horizontal Flat, Horizontal, Vertical	Flare-bevel-groove weld, sheet to supporting member	Thickness tested and thicker	Bend
 Flare-V-groove, sheet to sheet	Flat Horizontal Vertical Overhead	Flat Flat, Horizontal Flat, Horizontal, Vertical Flat, Horizontal, Overhead	Flare-V-groove weld, sheet to sheet; or Flare-bevel-groove weld, sheet to sheet, or sheet to supporting member	Thickness tested and thicker	Bend

* two tests required for certification

Figure 36-3. *For sheet steel welding, the position, weld joint, and thickness that are tested are typically the only variables for which the welder is qualified, per test.*

Brazing Performance Qualification Joint Designs
Figure 36-4

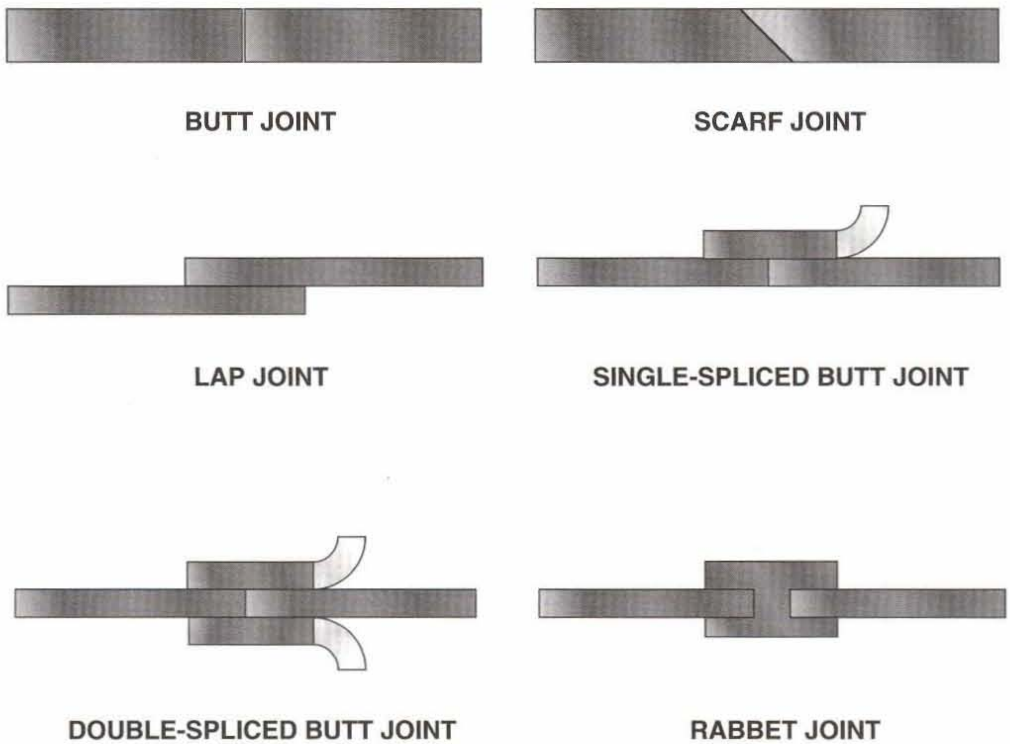


Figure 36-4. *WPQ for brazed joint is achieved by sectioning, polishing, and etching a test joint.*

POINTS TO REMEMBER

1. A welder performance qualification (WPQ) demonstrates a welder's ability to produce welds to meet the applicable WPS.
2. Qualification under one fabrication code or standard does not necessarily qualify a welder to weld under another code or standard, even though the qualification tests appear to be identical.
3. A PQR must include the essential welding variables, the range qualified, the type of tests, and the test results.
4. Structural welding code WPQ requirements are contained in AWS D1.1, *Structural Welding Code—Steel*.
5. The WPQ must be developed for the most difficult position expected during welding or brazing.

? QUESTIONS FOR STUDY AND DISCUSSION

1. Who is responsible for ensuring that qualification of welders meets applicable codes?
2. What is the difference between welder performance qualification and welder certification?
3. Are welders who meet the requirements for fillet welds automatically approved for groove welds?
4. When qualifying for pipe, in what position should the welder be qualified?

37 Welding Metallurgy

Welding metallurgy is the study of the effect of welding on the metallurgical structure of weld joints. Heat input during welding produces rapid heating, very high temperatures, and rapid cooling. The physical properties of the metal determine the response to the heat of welding. Mechanical properties of the metal, residual stresses, and corrosion resistance of metal are also affected by the heat of welding.

METALLURGICAL STRUCTURE

Metallurgy is the study of the influence of crystal and grain structure of metals on the mechanical, physical, and chemical properties of metals.

The crystal structure and grain structure of metals is known collectively as the metallurgical structure. *Metallurgical structure* is the arrangement of atoms in repeating patterns within a metal. The crystal structure is preserved in the grain structure of metals. The crystal structure may change as a metal is heated or cooled, or if the composition of the metal changes.

Crystal Structure

A *crystal structure* is a specific arrangement of atoms in an orderly and repeating three-dimensional pattern. All metals exhibit a crystal structure. Although 14 types of crystal structures are possible in nature, most metals exhibit one of three types: face-centered cubic, body-centered cubic, or close-packed hexagonal. See Figure 37-1.

The atomic arrangements in the different crystal structures lead to significant differences in the behavior of metals. Some metals, such as steel, may exhibit different crystal structures at different temperatures.

Grain Structure

Metals do not exist as a single crystal, but as a large number of grains. A *grain* is an assembly of crystals having different orientations of their crystal components. Grain structure develops as metals solidify from the molten state. The first atoms to solidify develop the characteristic crystal structure of the metal. Each solid crystal nucleus that forms develops its own orientation within the structure. The crystals grow by developing offshoots, but retain their orientation with respect to the

Crystal structure is a specific arrangement of the building blocks of matter (atoms) in an orderly and repeating three-dimensional pattern.

other nuclei. The solidifying structures are called dendrites. As the dendrites grow, they fill the space between themselves with offshoots and branches until their extremities meet other dendrites. The dendrites continue to grow until the space between them is completely filled and solidification is complete. See Figure 37-2.

Grain Structure
Figure 37-2

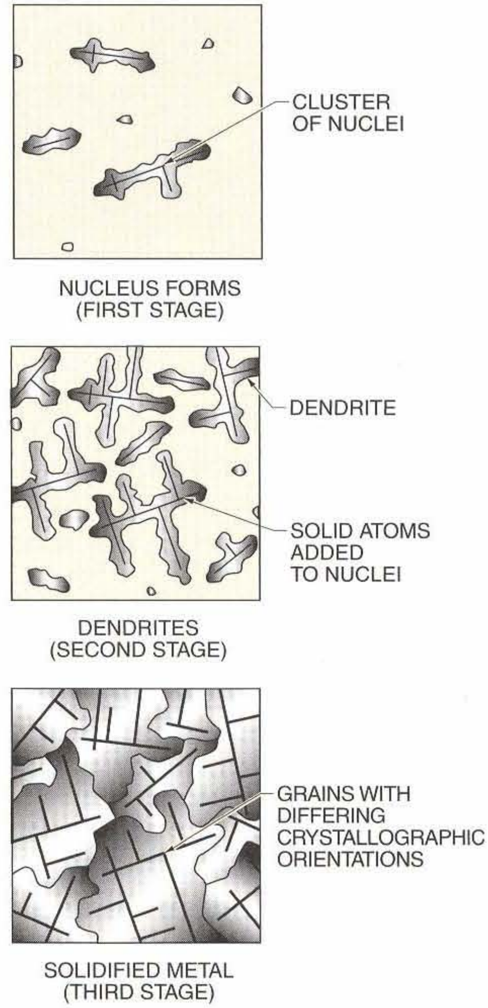


Figure 37-2. *The grain structure of crystals develops from the solidification and growth of many nuclei that form and grow as molten metal cools.*

Heat Input

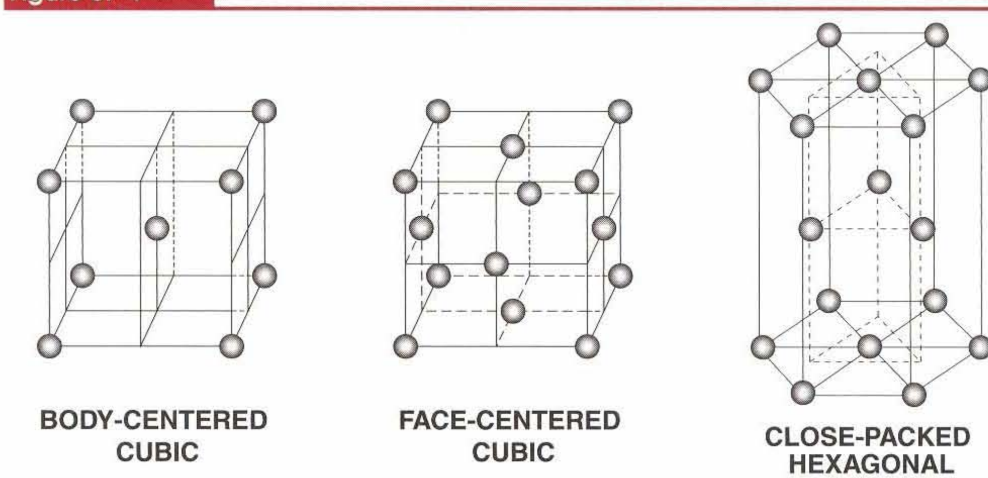
Heat input is the most important element for welding. Heat (heat input) is required to melt the base metal and filler metal during welding.

Heat is the most important element needed for welding. Heat (heat input) is required to melt the base metal and filler metal during welding. *Heat input* is the amount of heat applied to the filler metal and the base metal surface at the required rate to form a weld pool, plus the additional heat required to compensate for heat that is conducted away from the weld. Heat input during welding produces rapid heating, very high temperatures, and rapid cooling. See Figure 37-3.

The most common source of heat input in fusion welding is the electric arc. Other sources of heat input, such as burning oxygen and acetylene (oxyfuel welding), are also used. Controlling heat input is essential when welding because the heat input may affect the structure and properties of metals.

Figure 37-1. *As atoms cool from a liquid to a solid state, they are arranged into one of three crystal structure patterns: body-centered cubic, face-centered cubic, or close-packed hexagonal.*

Crystal Structures
Figure 37-1



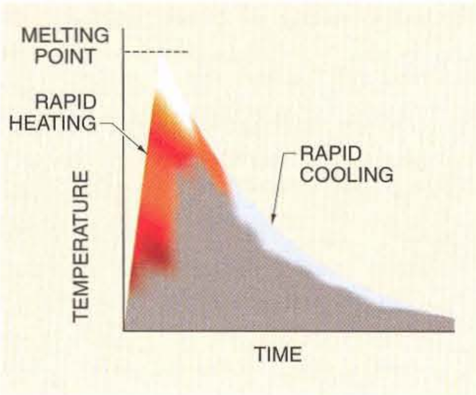


Figure 37-3. *Heat input during welding produces rapid heating, very high temperatures, and rapid cooling.*

Seventy percent to 85% of the heat generated in SMAW is used in making the weld. Most of the remaining heat is used to melt the base metal adjacent to the weld joint. The percentage of heat used to melt the filler metal varies with the welding process, welding procedure, base metal, and joint design. Additional heat is lost through heating the electrodes and flux, through weld spatter, and through convection to the surrounding atmosphere.

Calculating Heat Input. Heat input is measured in joules per linear inch of weld. The heat input produced by a moving electric arc is calculated using the following equation:

$$Heat\ input = \frac{WV \times WC}{WTS} \times 60$$

where

WV = welding voltage (in V)

WC = welding current (in A)

60 = constant (to convert min to sec)

WTS = welding travel speed (in in./min)

What is the heat input when using SMAW at 29 V, 300 A, and a travel speed of 18″/min?

$$Heat\ input = \frac{WV \times WC}{WTS} \times 60$$

$$Heat\ input = \frac{29 \times 300}{18} \times 60$$

$$Heat\ input = 483.3\overline{3} \times 60$$

Heat input = **29,000 Joules per inch**

Heating Rate. *Heating rate* is the rate of temperature change of a weld joint over time from room temperature to the welding temperature. The heating rate is influenced by heat input, thermal conductivity, and the mass of the joint area.

Heat input exceeds heat loss during welding and the base metal becomes hotter. The temperature of the work near the arc rises and as soon as the arc moves on, the temperature begins to fall. If the weld pool becomes large and unmanageable, it can be cooled by reducing the current or breaking the arc, thus reducing heat input or cutting it off completely.

The maximum temperature achieved in a weld must be sufficient to cause melting of the base metal at the weld face. The amount by which the temperature must exceed the melting point of the filler metal depends on the welding process. The time the metal is at the maximum temperature can influence properties of both the filler metal and the base metal.

Cooling Rate. The *cooling rate* is the rate of temperature change of a weld joint over time from the welding temperature to room temperature. Weld joint cooling takes place at a much faster rate than any quenching process in heat treatment. The cooling rate rapidly decreases with distance from the weld, because the surrounding base metal acts as an effective heat sink.

The cooling rate is governed by factors such as heat loss, thermal conductivity of the base metal, and the amount of preheat and interpass temperature control required. *Preheat* is the heating of the joint area to a predetermined temperature in order to slow the cooling rate. *Interpass temperature control* is maintaining the temperature range within the weld between weld passes until welding is complete. Depending on the type of metal being welded, interpass temperature control may have an upper limit, a lower limit, or both.

> The way steel reacts to heat input and cooling is a function of its chemical elements and their effect on the metallurgical structure. The cooling rate is determined by the steel composition and must be controlled to prevent embrittlement in susceptible compositions.

> *Using the proper preheat temperature, coupled with an upper limit on interpass temperature control, helps maintain the cooling rate below the critical cooling rate, preventing loss of toughness.*

When using medium-carbon and low-alloy steels, the rate of cooling must be controlled to maintain toughness of the heat-affected zone. There is a critical cooling rate for each type of steel, which, if exceeded, leads to loss of toughness. Using the proper preheat temperature, coupled with an upper limit on interpass temperature control, helps maintain the cooling rate below the critical cooling rate. The cooling rate of a weld also depends on the number of weld passes required. The root bead has the greatest preheating effect on the weld joint. The change in the cooling rate between subsequent passes is less significant.

Forced cooling may be used to accelerate cooling. *Forced cooling* is rapid cooling of a solidified weld joint between passes using water. Forced cooling is often used because it increases production. Forced cooling is most common with stainless steels, but is also used on other alloys. Abnormal stresses and other detrimental effects may be exerted on the joint integrity when forced cooling is used.

> *The three key regions of a weld are the weld metal, the base metal, and the heat-affected zone.*

Slow Cooling of Steel. When steel is slow cooled from a high temperature, metallurgical structure changes occur under conditions of thermal equilibrium. *Thermal equilibrium* is a steady-state condition in which time is available for the diffusion of atoms. Austenite (which has a face-centered cubic crystal structure) transforms on cooling to a mixture of ferrite (which has a body-centered cubic structure) and iron carbide. Iron carbide is a compound formed from carbon that diffuses out of the austenite and combines with some of the ferrite. Slow cooling is used in heat treatment processes such as annealing that are designed to soften steel.

Rapid Cooling of Steel. Rapid cooling is used to strengthen steel. The steel is heated to a high temperature to produce austenite—a process called austenitizing—and then rapidly cooled, or quenched. When steel is rapidly cooled, an equilibrium-dependent structure change has no time to occur. The steel is then heated to an intermediate temperature, or tempered, to restore sufficient ductility while maintaining a stronger, harder product.

Welding produces metallurgical structure changes similar to the quenching stage of heat treatment. Consequently, as the carbon content of steel increases, the welding procedure must be manipulated to "cushion" the effect of quenching. This is achieved by preheating or blanket cooling. Steel may also be tempered after welding using postheating, which reduces hardness and residual stresses.

WELD REGIONS

The heat of welding creates three regions, with different metallurgical structures, within a weld joint. These regions are weld metal, heat-affected zone (HAZ), and base metal. See Figure 37-4. Additionally, surfacing and buttering procedures create regions with properties similar to the weld metal, HAZ, or base metal.

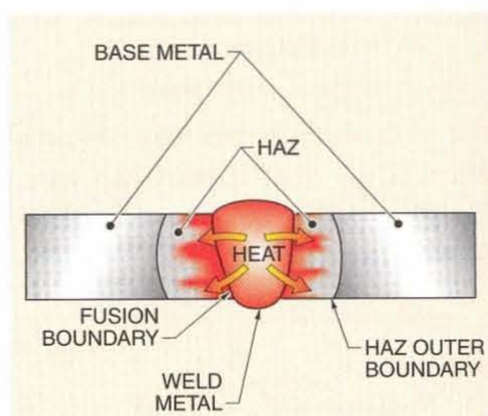


Figure 37-4. *The heat of welding creates three regions of metallurgical structures: weld metal, heat-affected zone (HAZ), and base metal.*

Weld Metal

Weld metal is the portion of a fusion weld that is completely melted during welding. Weld metal consists of solidified weld filler metal resulting from the addition of filler metal to the joint, plus a small amount of melted base metal at its boundaries, which creates the weld interface. The *weld interface* is the boundary between the weld metal and the base metal in a fusion weld. The melted base metal contributes to dilution if a filler metal of different composition is used.

Dilution modifies the chemical composition of filler metal because of mixing with the base metal or previously applied weld metal in the weld bead. *Dissimilar metal welding* is the joining of two metals of different composition using a compatible filler metal to ensure the weld meets required properties.

The amount of dilution varies with the heat input of the welding process. The greater the heat input required by the welding process, the greater the opportunity for dilution in the weld metal. For SMAW in horizontal position, a dilution rate of 30% is used to calculate the deposited weld metal composition. In this case, 70% of the completed weld bead is supplied by the filler metal and 15% is supplied by each of the base metals. See Figure 37-5.

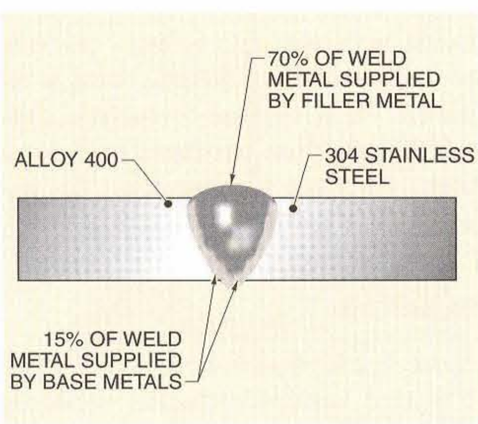


Figure 37-5. *When welding dissimilar metals, the chemical composition of the weld is made up of metal supplied by both the filler metal and the base metal.*

If alloy 400 (67% nickel, 32% copper) and 304 stainless steel (8% nickel, 18% chromium, 74% iron) are welded with ENiCrFe-2 (70% nickel, 15% chromium, 8% iron) filler metal, the diluted composition of the weld metal can be found by multiplying the filler metal composition by 70%, multiplying the base metal composition by 15%, and finally adding the corresponding amounts.

Contribution to weld metal by ENiCrFe-2 filler metal:

70% × 70% nickel = 49% nickel

70% × 15% chromium = 10.5% chromium

70% × 8% iron = 5.6% iron

Contribution to weld metal by alloy 400 base metal:

15% × 67% nickel = 10% nickel dilution

15% × 32% copper = 4.8% copper dilution

Contribution to weld metal by 304 stainless steel base metal:

15% × 8% nickel = 1.2% nickel dilution

15% × 18% chromium = 2.7% chromium dilution

15% × 74% iron = 11.1% iron dilution

The calculated composition of the weld metal is obtained by adding the filler metal contribution to the base metal contributions. For example:

(49% + 10% + 1.2%) = 60.2% nickel

(10.5% + 2.7%) = 13.2% chromium

(5.6% +11.1%) = 16.7% iron

plus 4.8% copper

The composition does not equal 100% because minor percentages of chemical elements in the base metal and filler metal are not included in the calculation. In a multiple-pass weld, the root bead is diluted equally by the base metals being welded. Subsequent passes are diluted partially by the base metal and partially by the previous weld bead.

The amount of dilution varies with the heat input of the welding process. The greater the heat input required by the welding process, the greater the opportunity for dilution in the weld metal.

The HAZ is a narrow band of base metal adjacent to the weld joint. Most problems that occur during welding occur in the HAZ.

Heat-Affected Zone (HAZ)

The heat-affected zone (HAZ) is a narrow band of base metal adjacent to the weld joint whose properties and/or metallurgical structure are altered by the heat of welding. With carbon steels, metallurgical structure changes can occur in any region of the base metal that exceeds 1350°F (732°C). With heat-treated aluminum alloys, any region heated above 600°F (315°C) experiences metallurgical structure transformation. Welding a heat-treated aluminum alloy creates an HAZ that may be weaker and more susceptible to failure under service loads.

The width of the HAZ is proportional to the amount of heat input during welding, and varies with the welding process used. It may extend from .06″ to .25″ into the base metal.

Base Metal

The base metal is the metal, after welding, that has not been structurally altered by exposure to heat. The boundary between the base metal and the HAZ depends on the temperature at which metallurgical structure transformation begins for any specific metal and is dependent on welding temperature.

Surfacing

It is usually necessary to apply two layers of surfacing weld to overcome dilution and attain the required wear or corrosion resistance properties.

Surfacing can be applied using the SMAW, GTAW, and GMAW arc welding processes. Surfacing can also be applied using OFW or brazing. Arc welding processes generally produce the most dilution. It is usually necessary to apply two layers of surfacing weld to overcome dilution and ensure the second layer has the required chemical composition or other properties. See Figure 37-6. A surfacing weld is applied to a surface, as opposed to a joint, to obtain the desired properties or dimensions.

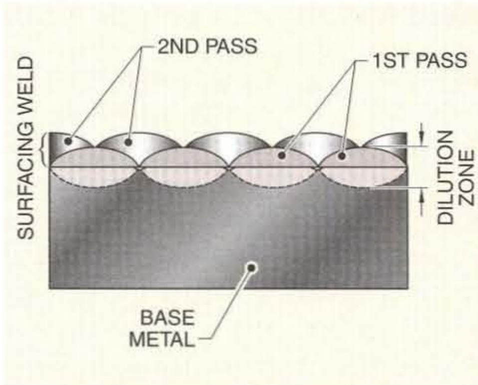


Figure 37-6. *Surfacing welds may require two or more passes to achieve the required chemical composition at the surface.*

SMAW produces high deposition rates with some dilution. Surface cleanliness requirements are less stringent than other processes. Some porosity and cracking may occur but are acceptable for applications in which SMAW surfacing is used.

GTAW produces very clean deposits with relatively low deposition rates. The surface must be thoroughly cleaned. The high heat input possible with GTAW increases the tendency for dilution and cracking because of stresses from expansion and contraction.

GMAW produces high deposition rates with low dilution; however, GMAW is not widely used for surfacing. A flux-cored electrode may be substituted for bare wire.

OFW produces a lower deposition rate compared with other processes, but produces the least dilution. The lower temperature gradient created in an OFW surfacing weld reduces cracking or spalling because thermal stress is reduced. OFW is used to surface steel when maximum hardness and minimum cracking are required, for example at a sealing face.

Buttering

Buttering is a surfacing weld variation that applies surfacing metal on one or more joint surfaces to provide compatible base metal for subsequent

completion of the weld. A significant difference in melting temperatures between two base metals or between a weld metal and a base metal may cause the metal with the lower melting temperature to rupture from shrinkage stresses as it solidifies and cools. The problem may be solved by buttering the face of the higher melting base metal with a filler metal of an intermediate melting temperature, reducing the melting temperature differential between the two metals. The weld is then made between the buttered face and the other base metal.

Buttering is also used to eliminate the need for preheat and postheating when welding two components, such as a medium-carbon steel fixture that is welded to a low-carbon steel part. The medium-carbon steel fixture is buttered with austenitic stainless steel filler metal and postheated to restore toughness. The buttered carbon steel may be welded to the low-carbon steel without preheat or postheating because austenitic stainless steel does not require preheat or postheating. See Figure 37-7.

Buttering is a method of applying a layer of metal to one side of a weld joint so that both halves of a joint can be welded together without needing to preheat and/or postheat the entire joint.

EFFECT OF WELDING ON PHYSICAL PROPERTIES

Physical properties are the characteristic responses of metal to forms of energy such as heat, light, electricity, and magnetism. Some physical properties of metals significantly influence weldability of a metal, but are not altered by welding. Other properties may be altered by welding. Physical properties that influence the weldability of metals include melting point, thermal expansion, specific heat, thermal conductivity, electrical conductivity, magnetism, and oxidation.

Physical properties of metal include melting point, thermal expansion, specific heat, thermal conductivity, electrical conductivity, magnetism, and oxidation.

Buttering
Figure 37-7

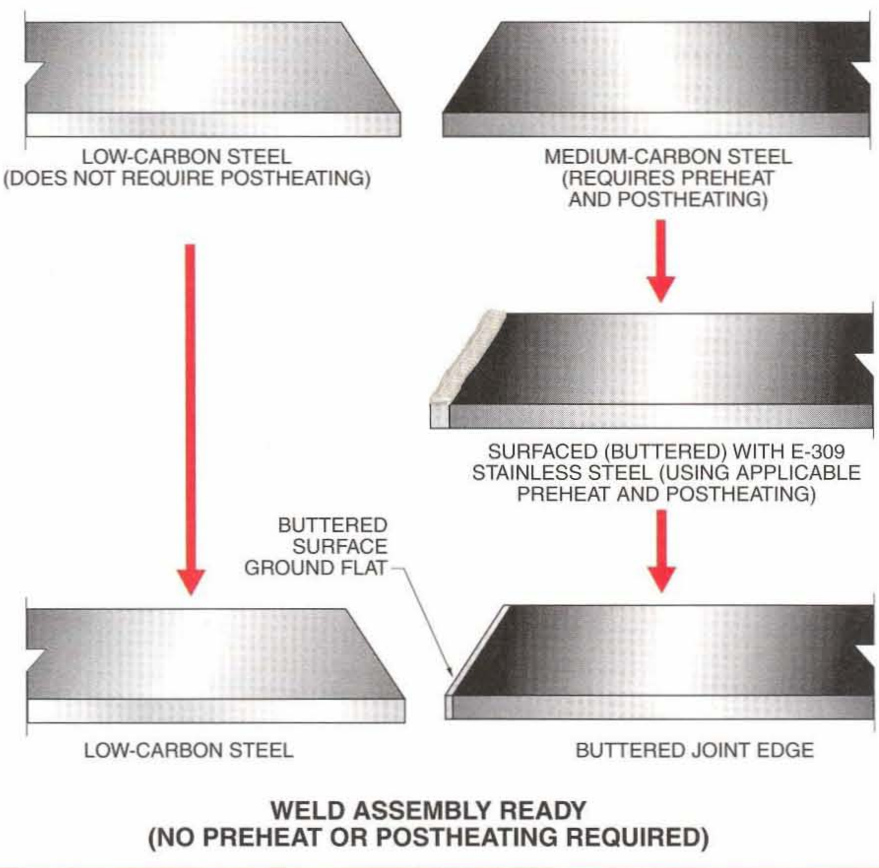


Figure 37-7. *Buttering is a method of avoiding preheat and postheating when welding structural components with different melting temperatures.*

Melting Point

Melting point is the temperature at which a metal passes from a solid state to a liquid (molten) state. Pure metals possess a specific melting point and pass from solid to liquid at a constant temperature. Alloys melt within a temperature range that depends on the alloy composition. The range of temperatures is bounded by the solidus and the liquidus. *Solidus* is the highest temperature at which an alloy is completely solid. *Liquidus* is the lowest temperature at which an alloy is completely molten. Melting begins at the solidus and is complete at the liquidus. Metals with low melting temperatures can be welded with low-temperature heat sources. See Figure 37-8.

Thermal Expansion

Thermal expansion is a measure of the change in dimension of a member caused by heating or cooling. Dimensional changes can occur in the length, width, and/or thickness. See Figure 37-9. The amount of thermal expansion is usually expressed as the coefficient of linear expansion (length). *Coefficient of linear expansion* is the change in the unit dimensions of a material caused by a 1° rise in temperature. See Figure 37-10. To calculate linear expansion, apply the formula:

$$C = \frac{Ld}{\Delta T}$$

where

C = coefficient of linear expansion

Ld = length differential per inch

ΔT = temperature differential in °F (or °C)

For example, what is the coefficient of linear expansion of a 10″ steel bar that increases to 10.00—1625″ when its temperature is increased from 1000°F to 1100°F?

$$C = \frac{Ld}{\Delta T}$$

$$C = \frac{.0001625}{100°\text{F}}$$

$C = .000001625''/°\text{F}$

$C =$ **1.1625 microinches per inch per degree F**

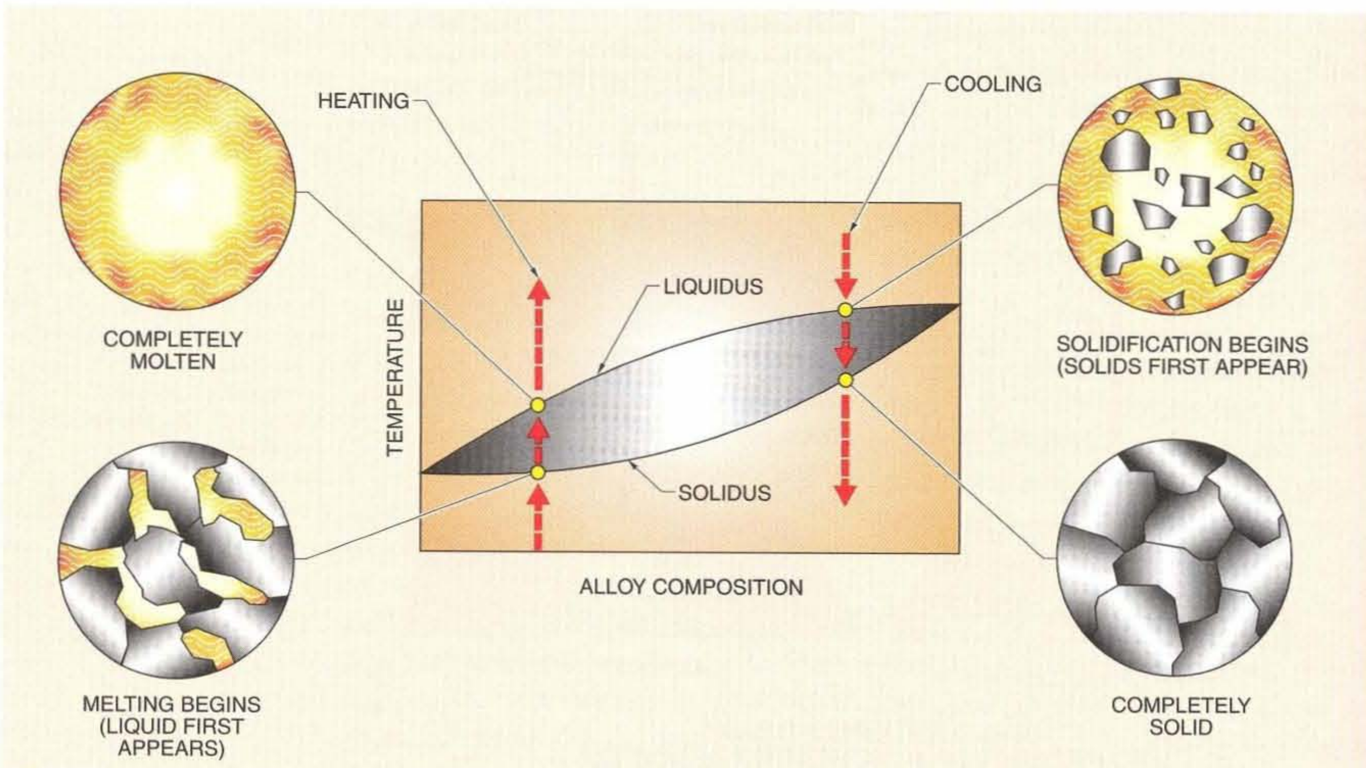


Figure 37-8. *The solidus and liquidus bracket the boundary temperatures between which an alloy is partially molten.*

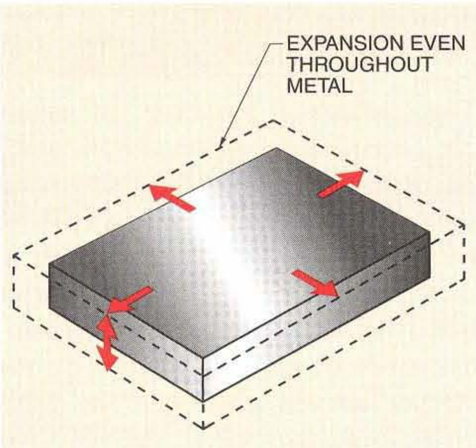


Figure 37-9. *Thermal expansion occurs in the length, the width, and/or the thickness.*

COEFFICIENT OF THERMAL EXPANSION FOR VARIOUS METALS	
Alloy	**Coefficient of Thermal Expansion***
Aluminum 1100	13.1
Aluminum 3003	12.8
Aluminum, pure	13.1
Aluminum 6061	13.0
Aluminum 7075	12.9
Aluminum 356.0	11.8
Copper, pure	9.16
Copper, oxygen-free	9.83
Brass, 85%	10.4
Brass, 80%	10.6
Brass, 70%	11.1
Manganese Bronze	11.7
Phosphor Bronze, 8%	10.1
70-30 Copper-Nickel	9.00
90-10 Copper-Nickel	9.50
Aluminum Bronze	9.11
Iron, pure	6.5
Mild Steel (.2%C)	6.5
Medium Carbon Steel (.4%C)	6.3
304 Stainless Steel	9.16
Nickel, pure	7.39
Monel®	7.77
Inconel®	6.39
Hastelloy C	6.28
Hastelloy X	7.67
Titanium	4.67
Silver	10.9
Zirconium	3.25
Invar	1.11
Gold	7.89

* in microinches per inch per degree Fahrenheit

Figure 37-10. *The coefficient of linear expansion may be used to calculate the change in dimensions of a metal with heating.*

Metals expand at different rates for the same temperature increase. Aluminum has the greatest expansion, increasing its dimensions almost twice as much as steel over a comparable temperature range. Thermal expansion in welding influences warpage control and fixture design and placement for the welding of similar and dissimilar metals.

Specific Heat

Specific heat is the ratio of the quantity of heat required to increase the temperature of a unit mass of metal by 1°, compared with the amount of heat required to raise the same mass of water by the same temperature. Specific heat is a way of comparing the amount of heat required to melt various metals.

A metal with a low melting point and high specific heat requires as much heat input to melt as a metal with high melting point and low specific heat. Aluminum, with a low melting point and high specific heat, requires almost the same amount of heat to melt as steel, which exhibits a higher melting point but lower specific heat.

Thermal Conductivity

Thermal conductivity is the rate at which metal transmits heat. In welding, thermal conductivity provides a measure for the heat input required to compensate for the rate at which heat is conducted away from the weld. Copper has a high thermal conductivity and is difficult to weld with low-temperature heat sources.

Austenitic stainless steel, with one-eighth the thermal conductivity of copper, requires a significantly lower heat input. The high thermal conductivity of copper makes it an excellent backing for welding. The rapid conduction of heat through copper backing prevents it from sticking to weld metal.

Mechanical properties describe the behavior of metals under mechanical loads and include strength, toughness, hardness, ductility, fatigue, creep, and malleability.

Electrical Conductivity

Electrical conductivity is the rate at which electric current flows through a metal. The higher the electrical conductivity of the metal, the more easily current flows through it. Electrical conductivity decreases as temperature increases, but room temperature values of electrical conductivity may be used for comparison between metals.

Electrical resistivity (resistivity) is the electrical resistance of a unit volume of a material. Resistivity is the reciprocal of electrical conductivity. Resistivity is the common method of expressing electrical conductivity. Metals with low resistivity (high electrical conductivity) are more conducive to resistance welding.

Magnetism

Magnetism is the ability of a metal to be attracted by a magnet, or to develop residual magnetism when placed in a magnetic or electrical field. This property is also known as ferromagnetism. Most steels are magnetic and may contain residual magnetism that can occur during magnetic particle inspection or from lifting with a magnet. Parts may need to be demagnetized before welding to prevent problems such as arc blow during welding. Arc blow causes the welding arc to deflect from its normal path because of magnetic forces.

Oxidation

Oxidation is the combination of a metal with oxygen in the air to form metal oxide. Every metal forms a thin oxide layer at room temperature. As temperatures increase, the oxide layer thickens. At welding temperature, steps must be taken to remove the metal oxide layer to prevent it from interfering with weld quality. Using flux-coated filler metals and inert gas welding prevents oxides from entering the weld area.

EFFECT OF WELDING ON MECHANICAL PROPERTIES

The mechanical properties of metals are classified using standards established by the American Society of Testing and Materials (ASTM). A *mechanical property* is a property of metal that describes the behavior of metals under applied loads. Mechanical properties are influenced by the composition and treatment of the metal.

Welding may alter specific mechanical properties of metals, leading to premature failure under load. The joint designer must consider the mechanical properties of metals when specifying the welds required. Welders should be familiar with basic terms and concepts associated with the mechanical properties of metals, such as strength, ductility, malleability, toughness, embrittlement, hardness, fatigue, and creep. An understanding of these concepts is often directly related to the ability to produce sound welds.

Strength

Strength is the ability of a metal to resist deformation from mechanical forces exerted on it. Deposited filler metal is usually stronger than the base metals it joins. It is necessary to use only the minimum amount of filler metal specified. Excess filler metal may be detrimental and exaggerate residual stress problems. Properly executed weld test specimens do not fail in the weld metal or HAZ when mechanically tested, but fail in the base metal. See Figure 37-11.

In a structure, welds are classified as primary or secondary. A *primary weld* is a weld that is an integral part of a structure and that directly transfers a load. A primary weld must possess or exceed the strength of the structural members. A *secondary weld* is a weld used to hold joint members and subassemblies together. Secondary welds are subjected to less stress and less load than primary welds.

Tensile Test Specimen
Figure 37-11

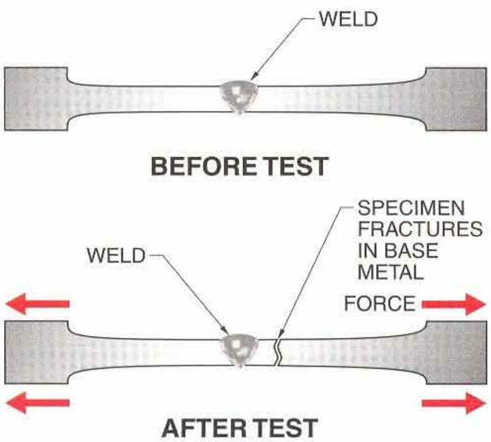


Figure 37-11. *Weld mechanical test samples should fail in the base metal.*

The strength properties of the metal being welded should be known, so that a strong, safe structure can be built. Likewise, when the strength of the weld is known as compared to the base metal, a weld joint strong enough to do the job can be produced.

Toughness

Toughness is the ability of a metal to absorb energy, such as impact loads, and deform rather than crack or fail catastrophically. Toughness is one of the most important metal mechanical properties. Weld procedures are designed to maintain toughness of the weld.

When heat-treatable steels are welded, the rapid cooling rate may cause an undesirable decrease in toughness of the HAZ. Proper methods of maintaining toughness must be used, such as preheat, interpass temperature control, or postheating.

Toughness is difficult to measure, but with steels, toughness correlates inversely with hardness, which is relatively easy to measure. High hardness in the HAZ may indicate low toughness in steels. Crack-like discontinuities may provide a stress concentration effect that causes the crack to propagate rapidly when a load is applied. See Figure 37-12. For this reason, fabrication codes do not permit cracks or crack-like discontinuities.

Welding procedures for steels in specific applications may require impact testing requirements to ensure that there is no loss of toughness in the HAZ. *Impact testing* is special testing performed on small, notched specimens, to simulate a stress concentration effect.

Toughness
Figure 37-12

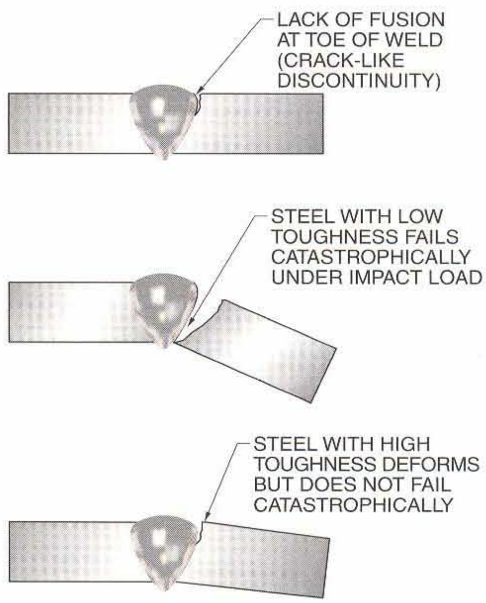


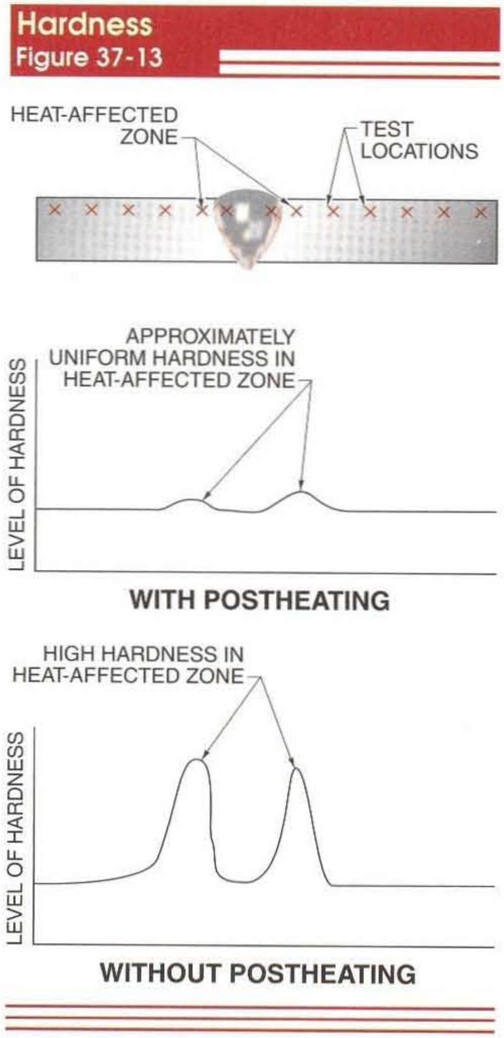
Figure 37-12. *Tough steel will absorb a sudden load, rather than crack catastrophically.*

Hardness

Hardness is the resistance of a material to deformation, indentation, or scratching. Hardness testing is one of the most widely used testing procedures because it is rapid, easy to use, and often nondestructive. Hardness is most often measured using indentation hardness tests, such as the Brinell test, the Rockwell test, or the Vickers test.

On steel, hardness can be used to estimate the toughness of a weld joint, especially where preheat, interpass temperature control, and/or postheating are used to ensure integrity. See Figure 37-13. It can also be used to predict scratching or scuffing resistance of a material.

Figure 37-13. *Hardness traverse made across a steel weld joint indicates whether there is a loss of toughness in the heat-affected zone.*



Ductility

Ductility is a measure of the ability of a metal to yield plastically under load, rather than fracture. High-ductility metals, such as copper, deform as the load on the metal is increased, eventually failing. Low-ductility metals, such as cast iron, deform only slightly and fail suddenly as the load is increased. Ductility is measured in tensile test samples by percentage elongation to failure, or percentage reduction of area to failure.

Embrittlement

Embrittlement is the complete loss of ductility and toughness of a metal, so that it fractures when a small load is applied. Embrittlement may be caused by applying the wrong brazing metal or when molten zinc contacts stainless steel. If galvanized steel is welded to stainless, the zinc adjacent to the weld region must be removed by sandblasting prior to welding. Embrittlement often occurs by penetration of the embrittling species into the grains of the metal (intergranular penetration).

Fatigue

Fatigue is failure of a material operating under alternating (cyclic) stresses at a value below the tensile strength of the material. Fatigue is a problem that affects the service life of any component that moves, rotates, vibrates, or is subject to thermal cycling. For example, a piston rod or an axle undergoes rapid and complete reversal of stresses from tension to compression.

Approximately 90% of all failures in engineering components are fatigue-related. Fatigue problems may be severe in welded structures since most welded joints have poor fatigue strength and finite fatigue life because of their shape, residual stresses, and discontinuities. All welding introduces stress concentrations into a weld, reducing fatigue strength; the effect is highest when the load is applied transversally to the weld.

Fatigue cracking initiates in the toe of the weld where stress concentrations are highest. Features that increase the strength of the weld, such as additional weld beads or inclusion of stiffeners, increase stress concentration and further reduce fatigue life. For this reason, attempting to fix a part that has failed in fatigue by adding a weld bead, or reinforcing with stiffeners welded to the structure, has the opposite effect and further reduces the life of the part. Although the weld itself is stronger under static load, weld discontinuities, coupled with the additional stress concentration, more than offset any strengthening effect. See Figure 37-14.

Fatigue
Figure 37-14

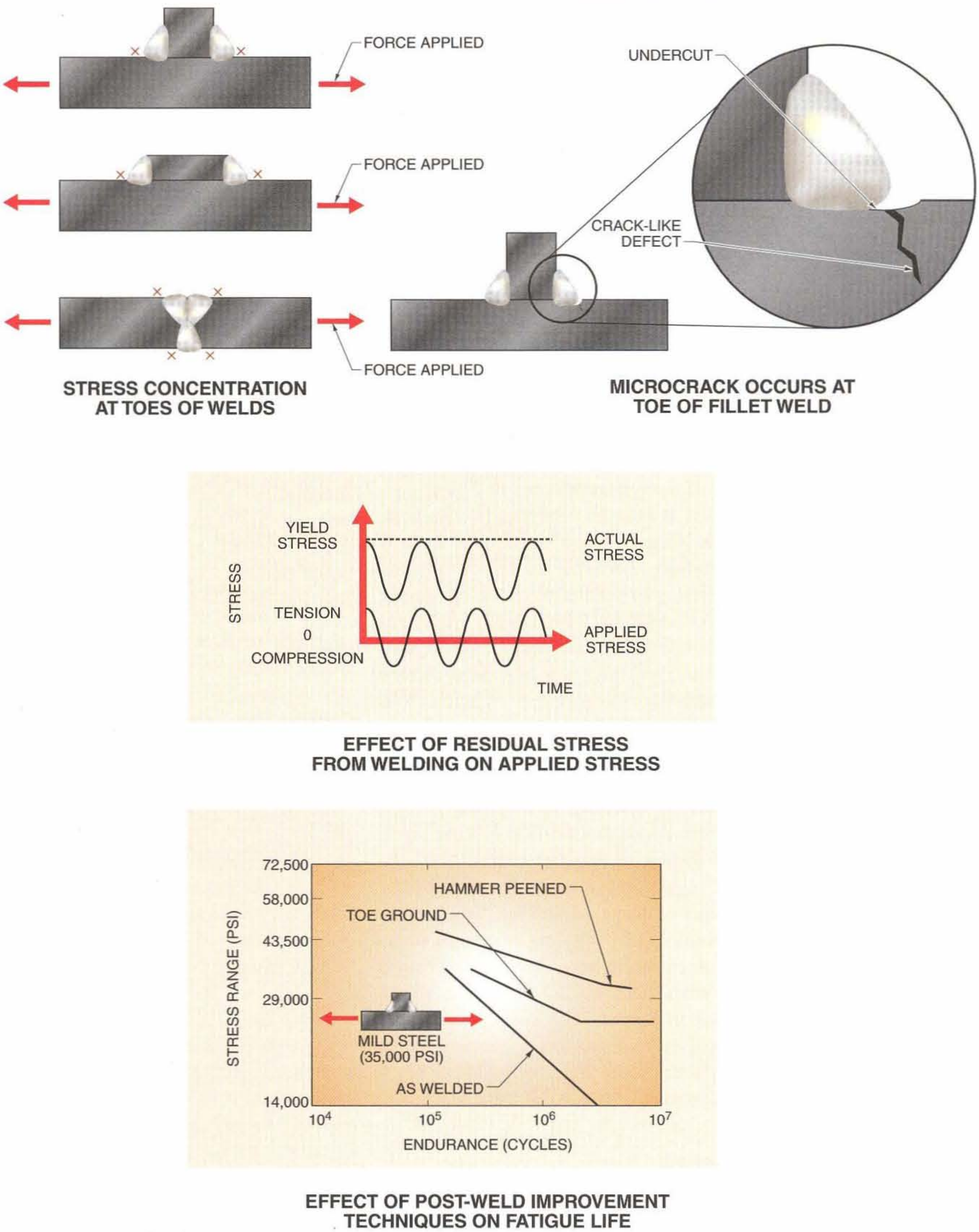


Figure 37-14. *Welding reduces the fatigue strength of structures.*

Fillet welds are particularly prone to failure by fatigue. During cooling of a fillet weld, the toe develops a microcrack about .005″ deep. The microcrack can grow into a full-scale fatigue crack and lead to premature failure. See Figure 37-15.

Figure 37-15. *Fillet welds are prone to fatigue failure. During cooling, a small crack can grow into a fatigue crack and lead to premature failure, as cooling can cause the crack to spread.*

If design improvement is not possible, it may be necessary to use post-weld improvement techniques such as grinding, peening, or GTAW plasma dressing of a fillet weld toe to remove microcracking. Post-weld improvements can increase fatigue life significantly, but must not introduce surface notch into the part.

Fatigue failures in welds are prevented by designing welds away from critical regions of high stress concentration. Welding in an area of high stress concentration is a leading cause of failure of rotating shafts. The area of high stress is where the shaft transitions to larger diameter. Welding or rebuilding by welding in a high stress concentration area, such as to rebuild a worn shaft, will lead to failure within a short period. The shaft must be rebuilt so that welding is carried out in locations away from the region of highest stress.

Creep

Creep is slow, plastic elongation that occurs during extended service under load above a specific temperature for that metal. Structural metals undergo creep at high temperatures. Creep-resistant alloys are used for high-temperature strength in petroleum refining, steam power generation, and other industries. Selecting the wrong filler metal or base metal may lead to premature failure from creep.

Malleability

Malleability is the ability of a metal to be deformed by compressive forces without developing defects such as those encountered in rolling, pressing, or forging.

Mechanical Force

Mechanical properties are characteristic responses of materials to mechanical forces. A *load* is an external mechanical force applied to a component. Standard terms used to describe the mechanical properties of solid metals include stress and strain. See Figure 37-16.

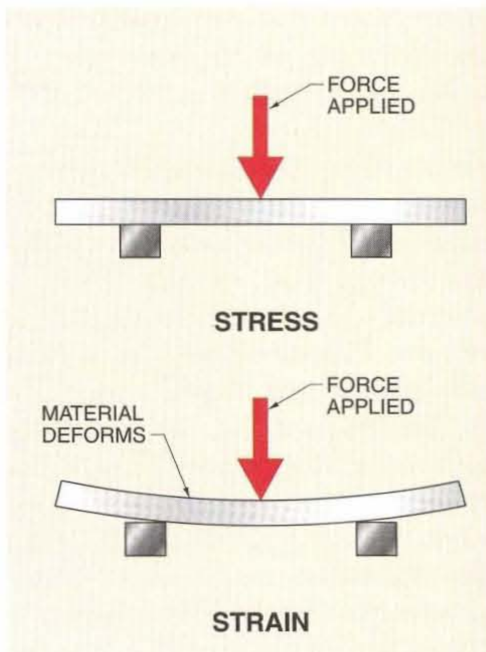


Figure 37-16. *Stress is the internal resistance of a material to an externally applied load. Stress is measured as the applied load over an area. Strain is the accompanying change in dimensions when a load induces stress in a material.*

Stress. *Stress* is the internal resistance of a material to an externally applied load. Stress is measured in terms of load divided by area. Every machine part or structural member is designed to safely withstand a certain amount of stress.

Strain. *Strain* is the accompanying change in dimensions when a load induces stress in a material. Strain is either elastic or plastic. Elastic strain occurs when a material is capable of returning to its original dimensions after removal of the load. For example, a spring with a normal load returns to its original length when the load is removed. Plastic strain occurs when a material is permanently deformed by the load. For example, an overloaded spring will develop a permanent set or an increase in length. As the load is steadily increased, a point is reached where the strain changes from elastic to plastic.

A *static load* is a load that remains constant. An example of a static load is a constant amount of water stored in a storage tank. An *impact load* is a load that is applied suddenly or intermittently. An example of an impact load is the action of a pile driver setting a pile.

A *cyclical (variable) load* is a load that varies with time and rate, but without the sudden change that occurs with an impact load. An example of a variable load is a revolving camshaft with a varying compressive and tensile load applied.

Mechanical Force Application. Mechanical force can be applied by five different methods: tension, compression, shear, torsion, and flexing. Combinations of methods may be applied under actual load conditions. See Figure 37-17.

Tension (tensile stress) is stress caused by two equal forces acting on the same axial line to pull an object apart. The magnitude of the stress depends on the amount of load placed on the object and the cross-sectional area of the object. The same load causes greater stress to an object with a small cross-sectional area than to an object with a large cross-sectional area.

Tensile strength is a measure of the maximum stress that a material can resist under tensile stress. Tensile stresses work to pull a material apart. The tensile strength of a metal is a primary factor to be considered in the evaluation of the metal. To find tensile stress, apply the formula:

$$St = \frac{F}{A}$$

where
St = tensile stress (in lb/sq in.)
F = force (in lb)
A = area (in sq in.)

For example, what is the tensile stress of an 8000 lb force applied to a square steel rod with a cross-sectional area of .50 sq in.?

$$St = \frac{F}{A}$$

$$St = \frac{8000}{.50}$$

$$St = \mathbf{16{,}000\ lb/sq\ in.}$$

Compression (compressive stress) is stress caused by two equal forces acting on the same axial line to crush an object. The deformation caused by compression consists of an increase in the cross-sectional area and a decrease in the original length of the object. *Compressive strength* is the ability of a material to resist being crushed. Nonmetallic materials, like brick, have high compressive strength compared to their tensile strength. To find compressive stress, apply the formula:

$$Sc = \frac{F}{A}$$

where
Sc = compressive stress (in lb/sq in.)
F = force (in lb)
A = area (in sq in.)

Mechanical force may be applied by tension, compression, shear stress, torsion, or flexural stress.

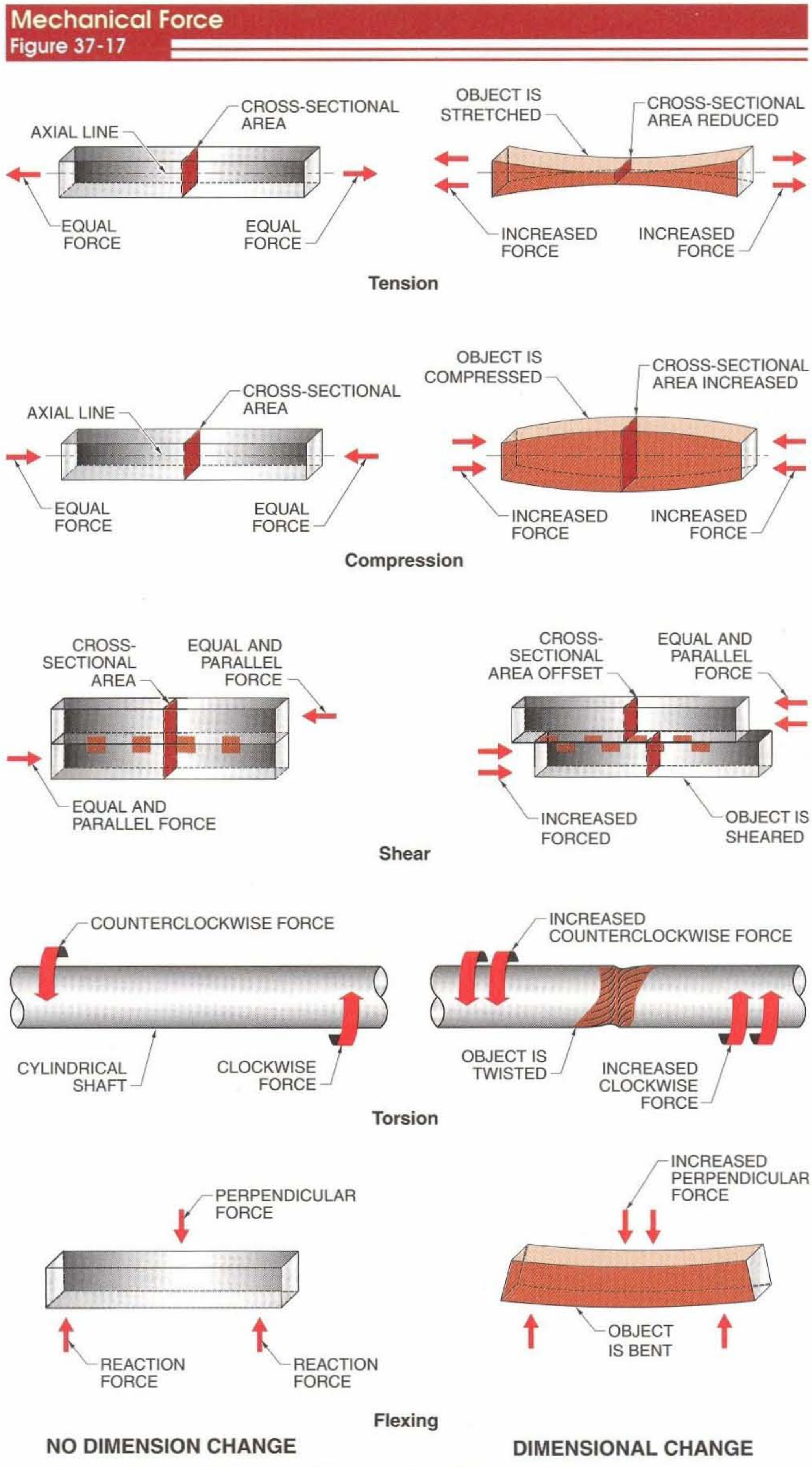
For example, what is the compressive stress of a 120,000 lb force applied to a rectangular cast iron bar with a cross-sectional area of 6 sq in.?

$$Sc = \frac{F}{A}$$

$$Sc = \frac{120{,}000}{6}$$

$$Sc = \mathbf{20{,}000\ lb/sq\ in.}$$

Figure 37-17. *A mechanical load may be applied using five different methods: tension, compression, shear, torsion, and flexing.*



The *modulus of elasticity* is a measure of the stiffness of an object under tension or compression. It is measured as the ratio of stress to strain for tensile or compressive forces that are within the elastic limit. Modulus of elasticity is an index of the ability of a solid material to deform when an external force is applied and then return to its original size and shape after the external force is removed. The less a material deforms under a given stress, the higher its modulus of elasticity.

The modulus of elasticity does not measure the amount of stretch a particular metal can take before breaking or deforming. It indicates how much stress is required to deform metal a given amount. See Figure 37-18. By checking the modulus of elasticity, the welder can ascertain the comparative stiffness of different materials. Rigidity (or stiffness) is an important consideration for many machine and structural applications. To find modulus of elasticity, apply the formula:

$$E = \frac{Ss}{Sn}$$

where

E = modulus of elasticity in millions of pounds per square inch (10^6 psi)

Ss = stress in pounds per square inch (psi)

Sn = strain in inch per inch (in./in.)

For example, what is the modulus of elasticity of a 1″ square piece of metal subjected to 40,000 lb of tension (stress) and exhibiting .001 in./in. strain?

$$E = \frac{Ss}{Sn}$$

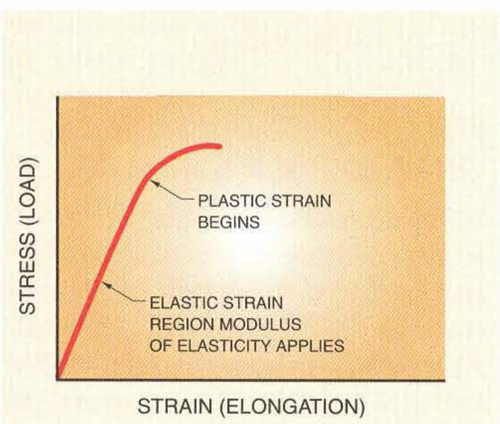
$$E = \frac{40{,}000}{.001}$$

$$E = 40{,}000{,}000$$

$$\mathbf{E = 40 \times 10^6\ psi}$$

Shear (shear stress) is stress caused by two equal and parallel forces acting upon an object from opposite directions. Shear stresses tend to cause one side of the object to slide in relation to the other side. Shear stress placed

Modulus of Elasticity
Figure 37-18



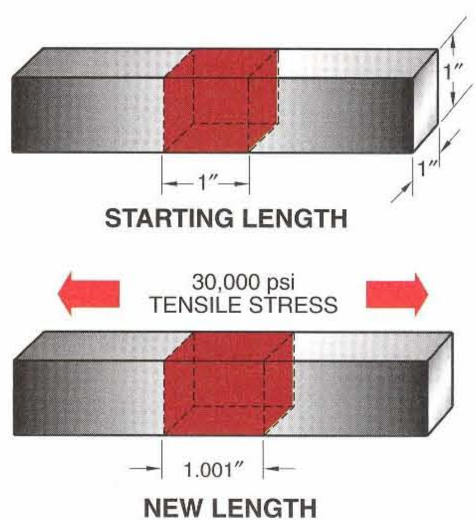


Figure 37-18. *Modulus of elasticity is a measure of stiffness and has no dimensions.*

on the cross-sectional area of an object is parallel to the force. The strength of materials under a shearing stress is less than under a tensile stress or a compressive stress. To find shear stress, apply the formula:

$$Ss = \frac{F}{A} \text{ or } F = Ss \times A$$

where

Ss = shearing stress (in lb/sq in.)
F = force (in lb)
A = area (in sq in.)

For example, a .750″ hole is to be punched in a steel plate .5″ thick. What is the required force of the press if the ultimate strength of the steel plate in shear is 42,000 lb/sq in.?

The shear cross-sectional area (A) is equal to the circumference of the hole times the thickness of the plate (3.14 × .750 × .5 = 1.1775).

$F = Ss \times A$
$F = 42{,}000 \times 1.1775$
$F = \mathbf{49{,}455\ lb}$

Torsion (torsional stress) is stress caused by two forces acting in opposite twisting directions. Shafts used to transfer rotary motion are subject to torsional stress. The shafts are twisted by excessive torque, expressed in inch-pounds (in-lb). *Torque* is the product of the applied force (F) times the distance (L) from the center of the application. *Torsional strength* is the measure of a material's ability to withstand forces that cause it to twist. To find torque, apply the formula:

Welding creates significant stresses in joints, resulting in shrinkage stresses and residual stresses that may lead to cracking.

$T = F \times L$

where

T = torque (in in-lb)
F = force (in lb)
L = distance (in in.)

For example, what is the torque of a 160 lb force applied over a distance of 12″?

$T = F \times L$
$T = 160 \times 12$
$T = \mathbf{1920\ in\text{-}lb}$

Flexing (flexural or bending stress) is stress caused by equal forces acting perpendicular to the horizontal axis of an object. Bending stresses bend an object as the perpendicular force overcomes the reaction force. Bending stress is a combination of tensile stress and compressive stress. *Bending strength* is a combination of tensile and compressive forces, and is a property that measures resistance to bending or deflection in the direction that the load is applied.

Bending stress is commonly associated with beams and columns. The deformation caused by bending stress changes the shape of the object and creates a deflection. To find bending stress, apply the formula:

$$Sb = \frac{Mc}{Z}$$

where

Sb= bending stress (in lb/sq in.)
M = maximum bending movement (in in.-lb)
c = distance from neutral axis to farthest point in cross section (in in.)
Z = section modulus (in cu in.)

For example, what is the bending stress of a 1″ solid shaft subjected to a bending moment of 1400 in.-lb? The distance from the neutral axis to the cross-sectional area is .5″, and the section modulus is .049.

$$Sb = \frac{Mc}{Z}$$

$$Sb = \frac{1400 \times .5}{.049}$$

$Sb = 14{,}285.7143$
$Sb = \mathbf{14{,}286\ lb/sq\ in.}$

EFFECT OF WELDING STRESS ON WELDS

Welding creates significant stresses in joints, resulting in shrinkage stresses and residual stresses that may lead to cracking. Stress resulting from welding exerts a great influence on the behavior of welds in service. Stress types are shrinkage stress and residual stress.

Shrinkage Stress

Shrinkage stress is stress that occurs in weld filler metal as it cools, contracts, and solidifies. The solidifying

filler metal is relatively weak and has difficulty accommodating the stresses that result from shrinkage. Additionally, the last part of weld filler metal to solidify contains the lowest melting point constituents, increasing the weakness of the weld. See Figure 37-19.

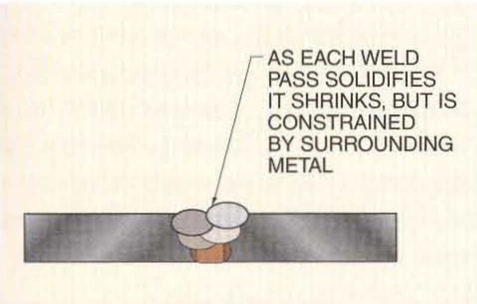


Figure 37-19. *Shrinkage of the weld during solidification imposes severe stress on the weld when it is in a relatively weak condition.*

Shrinkage stress problems are made worse when contaminants react with the solidifying weld filler metal to form weak or brittle microconstituents, or when the joint restrains (stiffens) the base metal, hampering shrinkage of the solidifying weld metal. Shrinkage stresses can cause hot cracks (hot cracking).

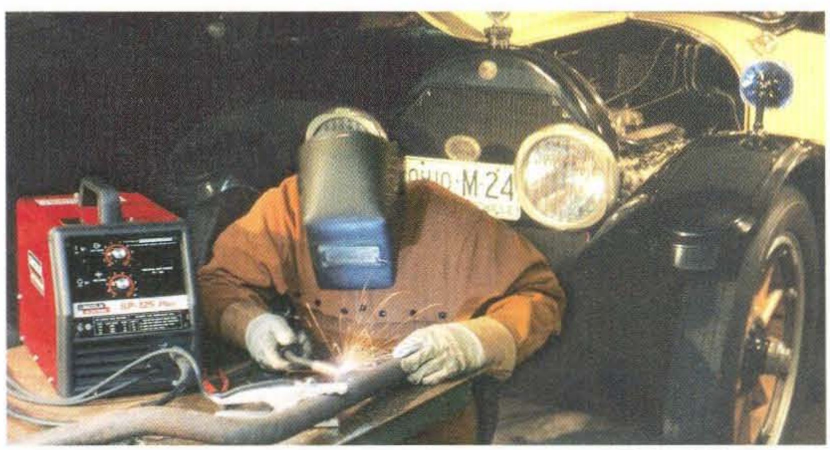
Contamination of the weld metal or excessive heat input during welding increases the susceptibility of the part to hot cracks. Nickel alloys may hot crack from the presence of even trace amounts of sulfur on the surface. Copper alloys may hot crack from excessive heat input.

Hot cracks may also occur if insufficient weld metal is added to a joint. When welding heavy-wall pipe, the wall thickness dictates whether it is possible to radiograph or dye check the root bead of weld filler metal to monitor its quality and decide whether any repairs are required. Excessive shrinkage stresses in heavy-wall pipe may cause a root bead to crack as it cools to ambient temperature from restraint in the joint. Thus, in heavy-wall pipe, it is necessary to make several weld passes before cooling to ambient temperature in order to create sufficient volume of weld metal to accommodate shrinkage stresses without cracking.

Residual Stress

Residual stress is stress that occurs in a joint member or material after welding has been completed, resulting from thermal or mechanical conditions. Almost every fabrication process introduces residual stress into metals. Residual stress from welding is often significantly higher than other fabrication processes. Residual stress may also be introduced into parts by post-fabrication procedures such as installation and assembly, occasional service overloads, ground settlement, and repair or modification.

As solidified weld metal cools to room temperature, the stresses within it increase and eventually exceed the yield strength of the base metal and the HAZ. *Yield strength* is the level of stress within a metal that is sufficient to cause plastic flow. Residual stress may cause cold cracking or distortion if the welded structure deforms to accommodate it. Cold cracking may be delayed hours or even days after the weld is finished. *Distortion* is the undesirable dimensional change of a fabrication. Distortion leads to out-of-specification dimensions or shape. See Figure 37-20.

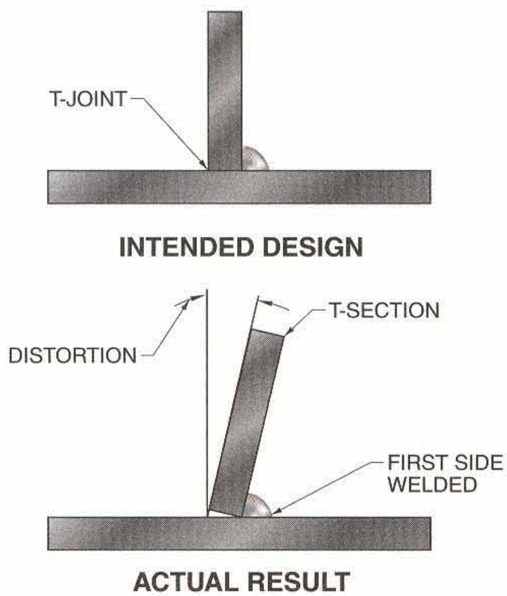


The Lincoln Electric Company

Residual stresses must be controlled during welding and during postproduction procedures, such as installation and assembly, to prevent defects such as cold cracking and distortion.

Figure 37-20. *Residual stress leads to many problems, such as distortion or loss of fatigue strength.*

Distortion
Figure 37-20



Residual stresses may be reduced using intermittent welding, low heat input welding, postheating, or peening.

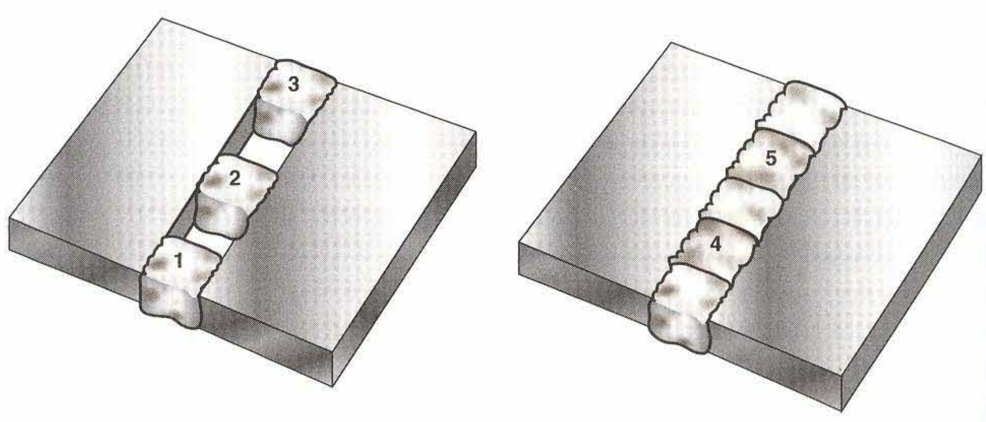
Residual Stress Reduction. To accommodate residual stresses and prevent distortion, welding procedures are designed to balance residual stresses across different parts of the weld. Methods of reducing residual stress include intermittent welding; low heat input welding with the use of heat sink and restraints; postheating; peening; and vibratory stress relief.

Intermittent welding is a stress-reduction technique in which the continuity of the weld is broken by recurring spaces between welds. Intermittent welding minimizes the heat input to the weld and lessens distortion. See Figure 37-21.

Residual stresses in welds must be controlled to prevent the occurrence of distortion in the weldment, premature failure of the weldment, or both.

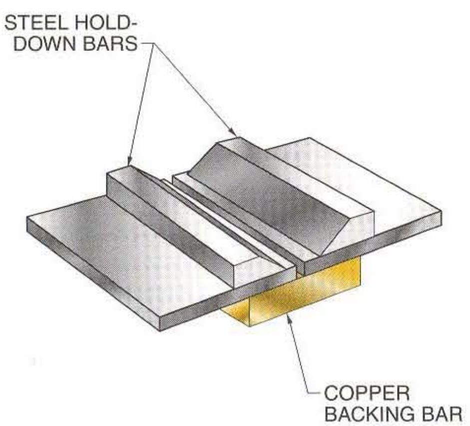
Figure 37-21. *An intermittent weld can be used to prevent distortion by minimizing heat input.*

Intermittent Welding
Figure 37-21



Low heat input welding is a stress-reduction technique that decreases the amount of heat applied to the weld. Low heat input welding might require a change in welding process, such as using GMAW instead of GTAW welding. Alternatively, a heat sink may be used to rapidly remove heat from the welded region, such as by using a copper backing bar. A *restraint* is a clamp or fixture used to reduce distortion by preventing movement of the weld during cooling, but which does not necessarily reduce residual stress. See Figure 37-22.

Controlling Distortion
Figure 37-22



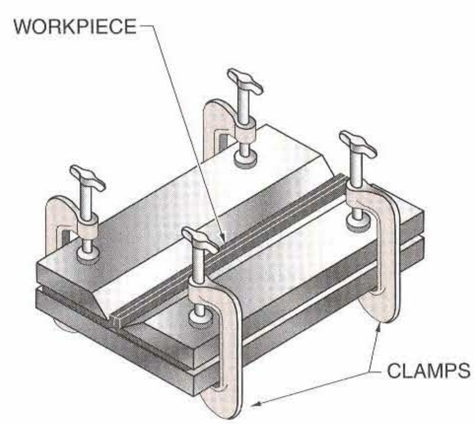


Figure 37-22. *Copper backing bars reduce heat and warpage of the weld area. Clamps and fixtures are used to hold pieces firmly together in position to prevent distortion.*

Postheating is the reheating of the weld area to a high temperature, holding for a predetermined time at temperature, and cooling at a specified rate. Postheating is used to prevent cold cracking from residual stresses. Postheating also stress-relieves the joint, reducing the possibility of distortion or cracking in service. With steels, postheating additionally tempers (softens and toughens) the weld. Postheating is often specified in conjunction with preheat and interpass temperature control.

Peening using a ball peen hammer relieves stresses in the metal by helping the metal stretch (yield) as it cools. See Figure 37-23. Peening reduces residual stress in the surface layers of a weld. Peening is performed for each weld pass immediately after solidification with impact blows. Peening induces compressive stresses and improves resistance to fatigue failure. Peening is not a substitute for the postheating required to restore toughness to a weld joint.

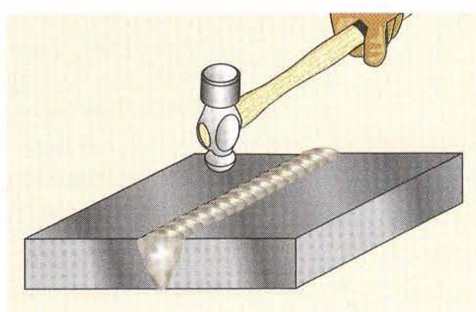


Figure 37-23. *Peening relieves internal stresses in a weld and helps the welded joint stretch as it cools.*

Vibratory stress relief is the application of subresonant vibration during welding to control distortion, or after cooling to provide stress relief. *Subresonant vibration* is vibration frequency less than the resonant frequency of the weld. Vibratory stress relief may control distortion during welding, but does not offer any significant stress relief. It should not be substituted for any specified preheat, interpass temperature control, or postheating procedure.

> *Welding creates chemical inhomogeneity in the weld joint, which leads to a loss of chemical resistance.*

> *An excessively hard HAZ, produced by rapid cooling from welding, may crack in certain chemical environments.*

EFFECT OF WELDING ON CORROSION RESISTANCE

The heat of welding can reduce the corrosion resistance of most metals. The loss of corrosion resistance may be caused by chemical inhomogeneity, residual stress, excessive hardness, or an undesirable microstructure.

Chemical Inhomogeneity

Welding creates chemical inhomogeneity, or segregation, in the weld joint. *Chemical inhomogeneity* is any disturbance in the chemical composition gradient of a metal. Chemical inhomogeneity leads to a loss of chemical resistance in corrosion-resistant alloys. Corrosion-resistant alloys must be welded with filler metals that do not reduce their corrosion resistance.

When similar base metals are welded, filler metal with a chemical composition similar to or slightly more corrosion-resistant than the base metal should be used. When dissimilar metals are welded, the filler metal must exceed the corrosion resistance of both metals. Dilution or segregation must not result in reduced corrosion resistance of the joint.

Segregation. *Segregation* is any concentration of alloying chemical elements in a specific region of a metal. Segregation can be an increased concentration or a depletion of chemical elements in the region. For example, molybdenum is added to stainless steels to improve their resistance to chloride-containing environments. When stainless steel base metal that contains 4.5% molybdenum is joined, matching filler metal with 4.5% molybdenum is not sufficient. Molydenum segregation occurs in the weld bead, leading to small molybdenum-depleted regions with inferior corrosion resistance. In this instance, filler metal with a molybdenum content higher than 4.5% must be used to compensate for segregation.

Residual Stress

Weld joints with high residual stress may be susceptible to corrosion in specific environments. Such welds are stress-relieved when necessary to prevent premature failure. Weld repair or burning is not permitted on stress-relieved equipment unless a welding procedure that incorporates stress relief is used. See Figure 37-24.

Excessive Hardness

An excessively hard HAZ, produced by rapid cooling from welding, may crack in certain chemical environments. Hard HAZs are also susceptible to hydrogen-assisted cracking from corrosion in service. *Hydrogen-assisted cracking* is loss of toughness in steels resulting from hydrogen atoms created at the surface of the metal by corrosion that diffuse into the HAZ and the base metal. Hydrogen diffusion interferes with the metal's ability to yield under stress, reducing its ductility and toughness.

When a corrosion reaction produces hydrogen atoms on the metal surface, the hydrogen atoms may or may not combine with one another. If they combine, hydrogen molecules are produced, which harmlessly dissipate from the metal surface. If they do not combine, the hydrogen atoms are extremely active and diffuse into the metal to cause hydrogen-assisted cracking.

Some species contained in corrosive environments, called poisons, are very harmful because they prevent, or "poison," the recombination of hydrogen atoms to hydrogen molecules. Poisons include sulfides such as hydrogen sulfide. Sulfide stress cracking is a form of hydrogen-assisted cracking that is a problem in the oil and gas production industry. Sulfide stress cracking is caused by the presence of hydrogen sulfide. Susceptibility of steels to hydrogen-assisted cracking increases with hardness of the steel.

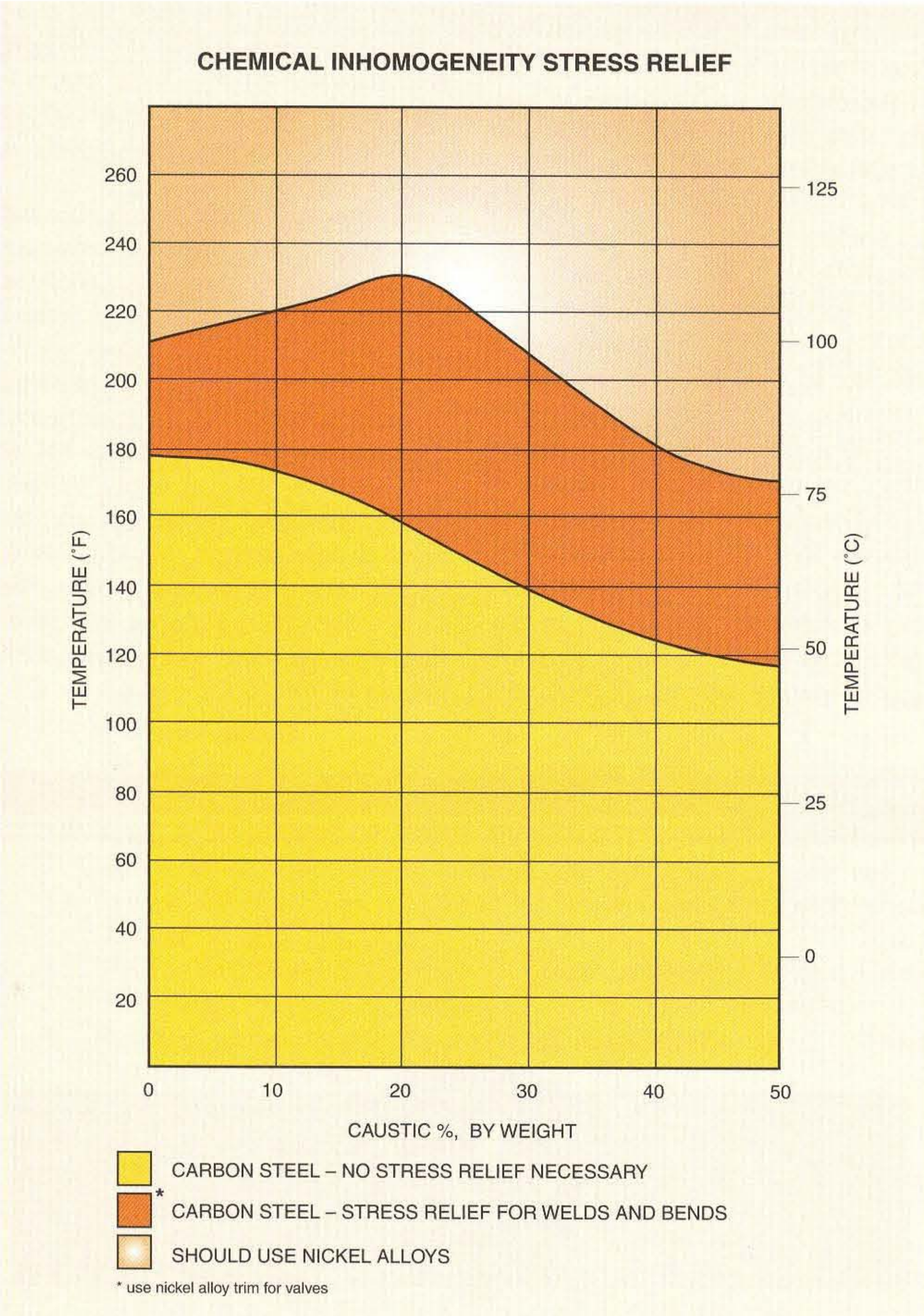


Figure 37-24. *Stress-relieved equipment should not be welded without a procedure that includes postheating.*

Welding operations can significantly affect the corrosion resistance of metal. How the welding process will affect the corrosion resistance of the metal must be considered before a particular metal is selected. Stress-relief must be performed on metals whose corrosion resistance may be affected during welding.

In environments containing poisons, carbon and low-alloy steels require proper preheat and postheating to reduce hardness in the HAZ to a value below Rockwell C 22 (22 HRC). Weld repairs that do not use adequate preheat and postheating may create an HAZ with excessive hardness.

Undesirable Microstructure

A *microstructure* is the appearance of the metallurgical structure of metals when they are specially prepared to reveal their features. See Figure 37-25. Microstructure is examined on polished and etched samples of metals, with a metallurgical microscope producing magnification from 100X to 1000X. The metallurgical structure of weld joints is revealed by examining their microstructure.

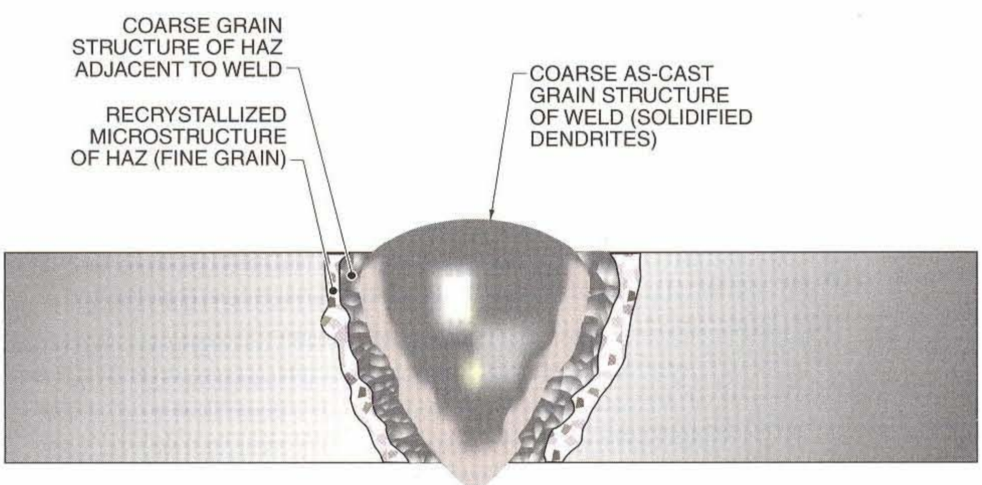
Chromium carbide within stainless steel reduces the corrosion resistance of the stainless steel. The reduced corrosion resistance of the stainless steel results in a line of deep corrosion in the HAZ when it is exposed to certain corrosive environments.

Undesirable microstructure is the creation, through the heat of welding, of microstructures that are preferentially attacked in a corrosive environment. For example, 304 or 316 stainless steels may develop an undesirable microstructure in the HAZ, known as sensitization, during welding. If conditions are favorable for sensitization, chromium and carbon within the stainless steel combine rapidly in the temperature range of 800°F (425°C) to 1500°F (815°C), and most rapidly at 1200°F (650°C).

Chromium carbide within stainless steel reduces the corrosion resistance of the stainless steel. The reduced corrosion resistance of the stainless steel results in a line of deep corrosion in the HAZ when it is exposed to certain corrosive environments. An extra-low-carbon grade of 304 or 316, such as 304L or 316L, or specially formulated grades that are immune to sensitization should be used. In the extra-low-carbon grades, the carbon content is reduced to a level that is insufficient to combine with the chromium in the metal.

Figure 37-25. *A metallurgical microstructure is the appearance of the metallurgical structure of metal when specially prepared to reveal its features.*

Metallurgical Microstructure
Figure 37-25

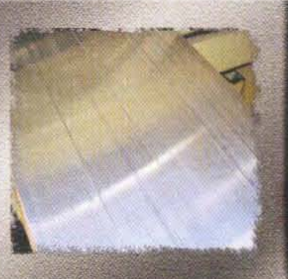


POINTS TO REMEMBER

1. Crystal structure is a specific arrangement of the building blocks of matter (atoms) in an orderly and repeating three-dimensional pattern.
2. Heat input is the most important element for welding. Heat (heat input) is required to melt the base metal and filler metal during welding.
3. Using the proper preheat temperature, coupled with an upper limit on interpass temperature control, helps maintain the cooling rate below the critical cooling rate, preventing loss of toughness.
4. The three key regions of a weld are the weld metal, the base metal, and the heat-affected zone.
5. The amount of dilution varies with the heat input of the welding process. The greater the heat input required by the welding process, the greater the opportunity for dilution in the weld metal.
6. The HAZ is a narrow band of base metal adjacent to the weld joint. Most problems that occur during welding occur in the HAZ.
7. It is usually necessary to apply two layers of surfacing weld to overcome dilution and attain the required wear or corrosion resistance properties.
8. Buttering is a method of applying a layer of metal to one side of a weld joint so that both halves of a joint can be welded together without needing to preheat and/or postheat the entire joint.
9. Physical properties of metal include melting point, thermal expansion, specific heat, thermal conductivity, electrical conductivity, magnetism, and oxidation.
10. Mechanical properties describe the behavior of metals under mechanical loads and include strength, toughness, hardness, ductility, fatigue, creep, and malleability.
11. Mechanical force may be applied by tension, compression, shear stress, torsion, or flexural stress.
12. Welding creates significant stresses in joints, resulting in shrinkage stresses and residual stresses that may lead to cracking.
13. Residual stresses may be reduced using intermittent welding, low heat input welding, postheating, or peening.
14. Welding creates chemical inhomogeneity in the weld joint, which leads to a loss of chemical resistance.
15. An excessively hard HAZ, produced by rapid cooling from welding, may crack in specific chemical environments.
16. Chromium carbide within stainless steel reduces the corrosion resistance of the stainless steel. The reduced corrosion resistance of the stainless steel results in a line of deep corrosion in the HAZ when it is exposed to certain corrosive environments.

QUESTIONS FOR STUDY AND DISCUSSION

1. When does the grain structure of a metal begin to develop?
2. What is the value of heat input with a welding current of 400 A at 45 V and a travel speed of 12″/min?
3. What is the effect of preheat on the cooling rate of the weld?
4. What is the effect of the heat of welding in the HAZ of an alloy that has been heat-treated?
5. Why must two layers of surfacing weld be used when applied using arc welding processes?
6. Why is copper a good material for use as a backing material?
7. What is the difference between strength and toughness?



Metal Identification

38

Welding Technology

Metal identification verifies as-received base metals and filler metals meet specifications. Metal identification is also required when the materials test report has been lost or physical identification markings have disappeared because of environmental wear. For critical welding work, supplementary metal identification may be required to verify conformance with purchase specifications.

Metals used in fabrication are typically specified on the weld prints. If a metal is not specified, qualified personnel must determine the metal to be used. Welders may be required to identify appropriate metals without assistance from qualified personnel during maintenance and repair tasks.

Many metal products such as pipe or plate are often purchased and stored for future use. Metals and filler metals can be identified before welding using visual identification, qualitative identification, semi-quantitative identification, and quantitative identification.

MANUFACTURER PAPERWORK

Manufacturer and supplier paperwork provides the initial means of checking specification compliance. *Paperwork* is physical certification or documentation provided by a product manufacturer or supplier. Paperwork may be hard copy or soft copy (computerized). The paperwork supplied by the manufacturer includes a materials test report (MTR), product analysis, and certificate of compliance (COC).

Materials Test Reports

A *materials test report (MTR)* is a certified statement issued by the primary manufacturer indicating the chemical analysis and mechanical properties of the metal. An MTR is also called a certificate of analysis (COA). Although an MTR is not formally required for all types of ASME code-approved metals used for code work, many companies require that an MTR accompany the metal.

An MTR allows the end user to ensure that the metal meets specified chemical composition and mechanical property requirements.

Manufacturers supply three types of paperwork to identify their products: materials test report, product analysis, and certificate of compliance.

Product Analysis

A *product analysis* is a chemical report that a particular metal, such as tubing or piping, is made from a particular heat of metal. Product analyses ensure that substitutions have not been made during processing of the metal. Product analyses are called out as supplemental requirements in ASTM specifications.

Certificate of Compliance

A *certificate of compliance (COC)* is a statement by a manufacturer, without supporting documentation, that the supplied metal meets specifications. A COC contains no test reports; it only states that, from the records, the manufacturer is confident no substitutions have been made. A COC can be issued for any metal.

A materials nonconformance report helps the end user document problems in received materials so that problem areas can be identified, corrected, and prevented in the future.

MATERIALS NONCONFORMANCE REPORT

A *materials nonconformance report* is a form created by the receiver of the metal to audit manufacturer paperwork regarding supplied metals. Analysis of materials nonconformance reports allows problem areas in metals acquisition to be identified, corrected, and prevented in the future. Materials nonconformance reports are only valuable if followed up by corrective programs. See Figure 38-1.

Harrington Hoists, Inc.

Materials can be identified by color and appearance, by a nameplate, or by markings stenciled on the end of the metal.

Consequences of Improper Materials Substitution

If improper metal substitutions are made, significant damage to equipment or injury to workers may result. For example, chrome-moly steels have a key use in critical applications, such as piping for handling high-temperature steam or hydrogen. Chrome-moly steels can easily be mistaken for carbon steels. They are similar in appearance to carbon steels, are magnetic like carbon steel, and rust like carbon steel if stored outdoors unprotected. However, substituting carbon steels for chrome-moly steels may result in catastrophic failure because, in a critical application, carbon steel is likely to fail before chrome-moly fails. Also, substituting the wrong type of metal, such as medium-carbon steel for low-carbon steel, nullifies the welding procedure and increases the chance of cracking.

VISUAL IDENTIFICATION

Visual identification is metal identification that consists of checking the appearance of the base metal or filler metal for key features that identify the metal type. Visual identification is performed by checking the appearance, color, nameplate, and markings of the metal.

Appearance

The appearance and shape of a metal may indicate the type of metal. Appearance includes the form and dimensions of metal components and parts. A hot-rolled structural shape in a steel-frame building would be low-carbon steel.

A rail would be identified by its shape as high-carbon steel. Many machine parts for light- and medium-duty industrial equipment and agricultural equipment are made of cast iron. Castings for heavy-duty work such as brake presses are commonly made of medium-carbon steel.

Materials Nonconformance Report
Figure 38-1

Materials Nonconformance Report

To be completed by field inspector or whoever discovers problem.
Keep one copy in the component file and submit one copy to
______________________ (appropriate area resource)

Equipment name______________ Number______________

Component name ______________ Number______________

Reason(s) for nonconformance ______________________

Supplier or replicator ______________________

Rebuilder (if applicable) ______________________

If rebuilt, by whom? ______________________

Specification(s) ______________________

Shipping procedures______________________

Receiving/stores procedures ______________________

Inspection procedures______________________

Material type ______________________

Dimensional requirement(s)______________________

Tolerances ______________________

Improper repairs or modifications ______________________

Installation Procedures ______________________

Other ______________________

____

Reported by ______________________

Figure 38-1. *A materials nonconformance report is a form created by the receiver of the metal to audit manufacturer paperwork regarding supplied metals.*

Color

The color of a metal is any specific hue that the metal typically exhibits. Some metals are relatively easy to distinguish by their color. Copper is reddish in color and easily identifiable. See Figure 38-2. Heat tint from heat-treating operations and surface scales and tarnishes from exposure to the environment may hide a metal's true color. To be sure of the true color, a small area of the surface must be cleaned by filing or rubbing with coarse abrasive paper. Color identification must not be used on metals that have suffered corrosion or oxidation that has resulted in surface color changes. See Figure 38-3.

Visual identification includes appearance, color, nameplate, and markings to determine key features that identify the metal type.

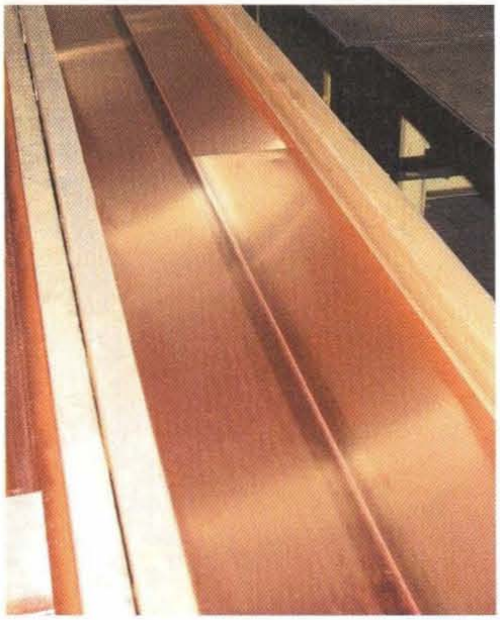


Figure 38-2. *Color is one key feature that can be used to visually identify metals such as copper.*

Nameplate

Fabricated equipment, such as heat exchangers or pressure vessels, must have a plaque or nameplate fixed to the exterior. The nameplate identifies the design, pressure and temperature rating, test pressure, and materials of construction. The nameplate must not be covered, damaged, or removed during the life of the equipment.

Markings

Markings may be embossed, stamped, stenciled, or attached to a part. Stamping and embossing are surface identification markings created by mechanical deformation on wrought products. On forgings, the stamped impression is produced with a metal die. The impression is usually located on the outside surface of the forging and consists of the ASTM or other materials standard, the pressure and temperature rating, and the forge shop logo.

Fasteners are identified by an embossed or stamped marking on either end of the fastener. Space is limited on fasteners, so a code is used to identify the standards organization and manufacturer. See Figure 38-4. The Industrial Fasteners Institute publishes a list of fastener manufacturers' logos. Metal markings consist of foundry marks, color-coding, and stencil marking.

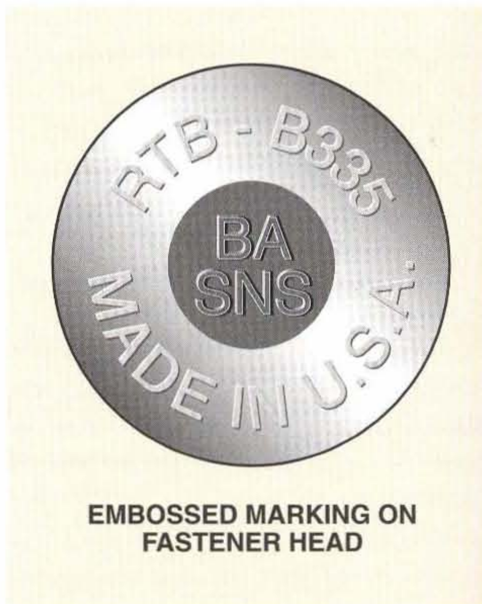
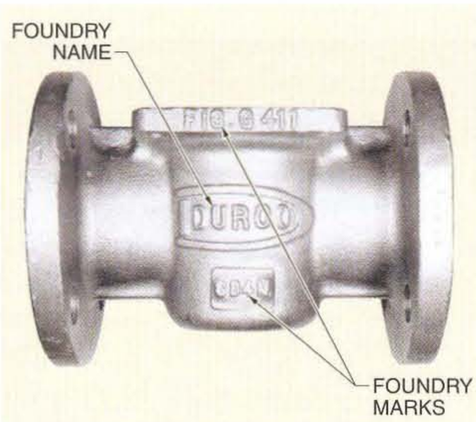


Figure 38-4. *An embossed marking on the head or other end of a fastener is one method of identifying fasteners.*

Figure 38-3. *Metals can be identified and grouped by the characteristic colors that the metal exhibits.*

CHARACTERISTIC COLOR GROUPINGS	
Color	**Metal**
Red or Reddish	Copper, >85 Copper Alloys
Light Brown or Tan	90% Cu/10% Ni (Copper-nickel)
Dark Yellow	Bronzes and Gold
Light Yellow	Brasses
Bluish or Dark Gray	Lead, Zinc, and Zinc Alloys
Silvery White with soft luster	Aluminum
Silvery White with bright luster	Stainless Steels
Gray	Carbon and Low-alloy Steels, 70% Cu/30% Ni (Copper-Nickel)
White or Gray	Nearly all others

Foundry Marks. A *foundry mark* is an identification marking embossed on the exterior of castings. Foundry marks are incorporated into the casting mold. Identification information includes the ASTM grade number, foundry name or logo, heat number, and foundry shorthand description for the alloy. When identifying castings by their foundry marks, the manufacturer's alloy codes must be known. See Figure 38-5.



The Duriron Company, Inc.

Figure 38-5. *Foundry marks are identification markings that are embossed on the exterior of castings.*

Color-Coding. *Color-coding* is an identification marking that consists of colored stripes painted on one end of metal to allow for permanent storage or temporary storage and subsequent retrieval from a metal service center or a user's storeroom.

Color-coding systems must clearly identify each metal. Since color-coding is set up to identify specific metals stored at a particular location, there is no universal color-coding system. To retain the color-coding system, metal must be cut from the end opposite the colored end. See Figure 38-6.

Stencil Marking. *Stencil marking* is an identification marking that consists of continuous or repeated ink markings on the metal. Stencil markings indicate alloy type, conformance to standards, and the dimensions of the metal. Stencil markings are repeated at regular intervals along the metal so the identification is not lost when the metal is cut or sectioned. Stencil markings are not permanent and may degrade during service or if stored outdoors.

Some chemical elements found in materials used for color-coding or stencil marking are potentially harmful. Chlorine (Cl), sulfur (S), and zinc (Zn) are some potentially harmful chemical elements that may be present. These chemical elements may cause catastrophic cracking in susceptible alloys such as stainless steel or high nickel alloy. Cracking is likely to occur when the paint or marking material on the metal is exposed to the heat of welding, to high-temperature service, or to corrosive environments in service. Marking materials that are used on susceptible alloys must contain low quantities (measured in parts per million, or ppm) of harmful chemical elements. No more than 250 ppm is allowable.

COLOR-CODING FOR SELECTED STEELS			
AISI-SAE Designation	Color	AISI-SAE Designation	Color
1010 Carbon Steel	White	4640 Molybdenum Steel	Green and Pink
1025 Carbon Steel	Red	3125 Nickel-Chromium Steel	Pink
1112 Free-cutting Steel	Yellow	3325 Nickel-Chromium Steel	Orange and Black
1120 Free-cutting Steel	Yellow and Brown	5120 Chromium Steel	Black
2015 Nickel Steel	Red and Brown	6115 Chromium-Vanadium Steel	White and Brown
2330 Nickel Steel	Red and White	7260 Tungsten Steel	Brown and Aluminum
4130 Molybdenum Steel	Green and White	9255 Silicon-Manganese	Bronze

Figure 38-6. *Color-coding allows easy and rapid identification of metals.*

Material markings are based on the materials designations assigned by classification societies such as the American Iron and Steel Institute (AISI), the Society of Automotive Engineers (SAE), or the American Society for Testing and Materials (ASTM).

Marking materials should be removed from the area of the metal to be welded, brazed, or soldered using an approved solvent. A marker with a fiber tip may be used to mark a metal. Because markers leave no solid residue that may lead to cracking, a solvent is not needed for removal.

QUALITATIVE IDENTIFICATION

Qualitative identification is metal identification by a qualified person to confirm the identity of an unknown metal. Qualitative identification has a relatively high degree of certainty for many applications. Qualitative identification techniques include magnetic response testing, chisel testing, torch testing, and file testing.

Magnetic Response Testing

Magnetic force is categorized as strong attraction, weak attraction, or no attraction. The category of magnetic response allows the unknown metal to be placed into a specific identification grouping.

Magnetic response testing is a qualitative identification method in which a magnet is laid on the surface of an unknown metal to test for a magnetic force. Magnetic force is categorized as strong attraction, weak attraction, or no attraction. See Figure 38-7. The category of magnetic response allows the unknown metal to be placed into a specific identification grouping.

The magnetism of a metal can change with temperature. As the temperature of some metals increases, the magnetism decreases. The point at which this change occurs is known as the Curie temperature. *Curie temperature* is the temperature of magnetic transformation, above which a metal is nonmagnetic, and below which it is magnetic. For some alloys, the magnetic transformation temperature may occur over a range of Curie temperatures. The effect of temperature on magnetic properties is illustrated in alloy 400 (Monel® 400), which is slightly magnetic at ambient temperature. Monel® 400 is nonmagnetic if its temperature is raised above the boiling point of water.

Magnetic behavior of some metals may change with mechanical processing. For example, 302 and 304 stainless steels, nonmagnetic in the annealed (soft) condition, become increasingly magnetic as they are cold-worked.

MAGNETIC FORCE

Strong Attraction:

- Carbon Steels
- Cast Irons
  - Gray
  - Ductile
  - Malleable
- Cobalt
- Iron-Silicon Alloys (.05% Si to 4.5% Si)
- Iron-Cobalt Alloys
- Iron-Molybdenum Alloys
- Low-Alloy Steels
- Nickel
- Stainless Steels
  - Ferritic
  - Martensitic (400 series)
  - Martensitic precipitation hardening
- Tool Steels

Weak Attraction:

- Stainless Steels
  - Cast 300 series
  - Cold-worked 302
  - Cold-worked 304
  - 308 weld metal
  - 309 weld metal
  - 329
- Monel® 400 (becomes nonmagnetic in boiling water)

No Attraction:

- Alloy 20 types
- Commercially pure nonferrous metals (except nickel and cobalt)
- Copper-Nickels
- Hastelloys®
- Incoloys®
- Inconels®
- Stainless Steels
  - Austenitic (other 300 series)
- Stellite®

Figure 38-7. *Metals can be identified and grouped by the magnetic force they produce.*

Minor microstructural differences between cast and wrought stainless steels can alter magnetic behavior. For example, E308 or ER308 filler metal for welding nonmagnetic, 304 stainless steel is slightly magnetic. The composition of the filler metal must be slightly magnetic to prevent hot cracking of the weld during cooling. Despite these minor complications, magnetic response testing is a convenient and rapid method of qualitative identification.

Chisel Testing

Chisel testing is a qualitative identification method that identifies metal by the shape of the chips it produces. Chisel testing consists of producing a chip by striking the edge or corner of the unknown metal with a chisel and hammer. Metal can be identified by the type of chips that result during chiseling. See Figure 38-8. The ease with which the chip breaks from the metal is an indication of the metal's hardness. The continuity of the chip indicates the metal's toughness. Long and curled chips result from mild steel and soft metals such as aluminum. Short, broken chips result from cast steel. High-carbon steels do not break easily and sample chips are difficult to obtain.

Torch Testing

Torch testing is a qualitative identification method that identifies a metal by the melting rate, the appearance of the metal when heat is applied, and the action of the molten metal. See Figure 38-9. These factors provide clues to the identity of the metal. Torch testing requires heating a small area of the surface of the unknown metal with a high-temperature oxyacetylene flame to cause local melting. To distinguish aluminum from magnesium, apply a torch to the filings. Magnesium burns with a sparking white flame.

CHISEL TEST IDENTIFICATION		
Type of Chip	**Type of Material**	**Possible Metal Type**
Continuous, easily removed	Ductile	Aluminum, Low-Carbon Steel, Malleable Iron
Fragmented small pieces, easily removed	Brittle	Gray Cast Iron
Fragmented or continuous, hard to remove	Brittle	High-Carbon Steel

Figure 38-8. *Metal can be identified by the type of chips that result during chiseling.*

TORCH TEST IDENTIFICATION		
Melting Rate	**Appearance of Metal After Heating**	**Possible Metal Type**
Slow, melts only after sufficient heat input	White metal	Aluminum
Fast, melts with little heat input	White metal	Zinc
Slow, melts only after sufficient heat input	Reddish metal	ETP Copper
Faster, melts with relatively little heat input	Reddish metal	Deoxidized Copper
Boils while melting	Reddish metal	Leaded Copper

Figure 38-9. *Torch testing identifies a metal by the melting rate and the appearance of the metal after heating.*

Semi-quantitative identification methods use a physical stimulus to provide a signal that may be compared with a set of standards. Semi-quantitative identification methods include density testing, spark testing, chemical spot testing, thermoelectric potential sorting, and optical emission spectroscopy.

When using the torch test, care must be taken to prevent damaging the sample. Heat input required to heat the sample varies depending on the type of metal being tested. If aluminum and zinc are being separated, the aluminum will not melt until sufficient heat has been applied because of its high thermal conductivity, whereas with zinc a sharp corner will melt quickly because zinc is not a good thermal conductor. In the case of leaded copper alloys, the surface will boil as the lead comes off.

File Testing

File testing is a qualitative identification method in which a file is used to indicate the hardness of steel compared with that of the file. File testing consists of assessing the degree of bite when a sharp mill file is drawn across the surface or edge of the unknown metal. See Figure 38-10. The file test provides a rapid and approximate method of estimating the hardness of steel. The easier the degree of bite, the softer the steel. The hardness of steel is a useful indicator of its weldability. The file test must be used with caution and only by qualified personnel.

SEMI-QUANTITATIVE IDENTIFICATION

Semi-quantitative identification is metal identification by applying a physical stimulus to an unknown metal to produce a signal that is interpreted against a set of standards. Semi-quantitative identification methods supported by documentation may be used in a formal quality control program. Semi-quantitative identification methods include density testing, spark testing, chemical spot testing, thermoelectric potential sorting, electrical resistivity testing, and optical emission spectroscopy.

Density Testing

Density testing is a semi-quantitative identification method that measures the density of an unknown metal. Density is measured by obtaining a small specimen of metal (½″ cube), a length of fine wire, an analytical balance, a small bench to straddle the analytical balance pan, and a 250 ml beaker that is filled approximately two-thirds full of distilled water.

FILE TEST IDENTIFICATION		
File Effect on Metal	**Brinell Hardness Number (BHN)**	**Possible Steel Type**
File easily bites into metal	100	Mild (Low-Carbon) Steel
File bites into metal with pressure	200	Medium-Carbon Steel
File only bites into metal with extreme pressure	300	High Alloy Steel-High Carbon Steel
Metal filed with difficulty	400	Unhardened Tool Steel
File leaves marks on metal but metal is nearly as hard as file	500	Hardened Tool Steel
Metal is harder than file	600+	Carbide Tool

Figure 38-10. *File testing consists of assessing the degree of bite when a sharp mill file is drawn across the surface or edge of the unknown metal.*

Dirt and foreign matter are thoroughly removed from the surface of the specimen. The specimen is washed with acetone and allowed to dry for 2 min to 3 min. The specimen is then weighed on an analytical balance to ± .001 g. The fine wire is also weighed to .001 g. The beaker containing the distilled water is placed on the small bench that straddles the balance pan. One end of the fine wire is tied firmly around the metal specimen.

The other end is attached to the balance hook so that the metal specimen is suspended and totally immersed in the distilled water. The metal specimen is reweighed when it is completely immersed in the distilled water. See Figure 38-11. The density of a metal is found by applying the following formula:

$$D = \frac{W_a}{W_a - (W_d - W_w)}$$

where

D = density (in g/cm^3)

W_a = weight of specimen (in g)

W_d = weight of specimen in distilled water (in g)

W_w = weight of fine wire (in g)

Density Testing
Figure 38-11

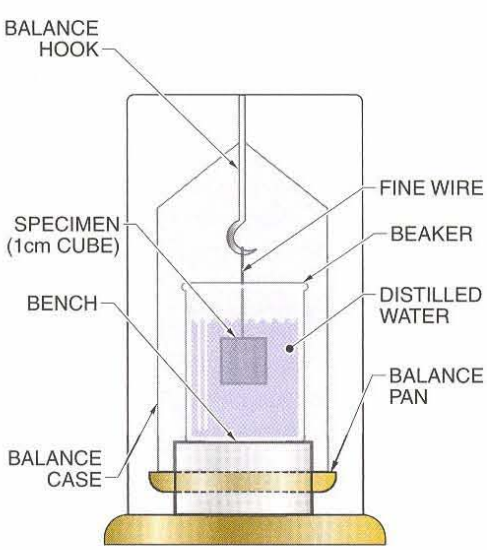


Figure 38-11. *Metals can be identified by measuring the density of the metal with an analytical balance.*

For example: What is the density of a specimen (1 cm cube) of 304 stainless steel that weighs 18.102 g in air, and weighs 15.960 g in the distilled water of an analytical balance, and that has a fine wire that weighs .151 g?

$$D = \frac{W_a}{W_a - (W_d - W_w)} \text{ g / cm}^3$$

$$D = \frac{18.102}{18.102 - (15.960 - .151)} \text{ g / cm}^3$$

$$D = \frac{18.102}{18.102 - 15.809} \text{ g / cm}^3$$

$$D = \frac{18.102}{2.293} \text{ g / cm}^3$$

$\mathbf{D = 7.89\ g/cm^3}$

The four density groupings for metals are very high density, high density, average density, and low density. From the figured value of density, metals are placed in one of the groupings. Depending on the separation of their density values, metals within the same group are distinguished from each other by checking the figured densities against a table of known density values. See Figure 38-12.

Metals are categorized as one of four density groupings, very high density, high density, average density, and low density, based on their figured density value.

Spark Testing

Spark testing is a semi-quantitative identification method that identifies metals by the shape, length, and color of the spark produced when the metal is held against a grinding wheel rotating at high speed. The chemical composition of the unknown steel influences the form of the spark stream produced. Spark stream characteristics are compared to standard spark stream charts to identify the unknown metal. See Figure 38-13.

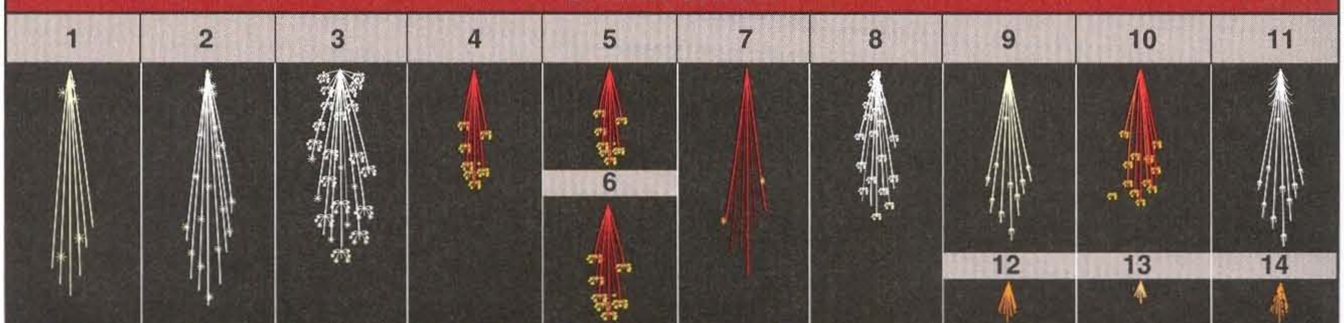
Spark testing conditions must be standardized, and testing should be conducted in diffused daylight rather than bright sunlight or darkness. The spark stream should not be exposed to heavy air drafts that may cause the tail of the spark stream to hook, leading to an erroneous interpretation. No objects should be allowed to obstruct the full-length view of the spark stream as it emanates from the grinding wheel.

Figure 38-12. *Figured density values can be used to place a metal in one of four groupings.*

DENSITY IDENTIFICATION GROUPINGS		
Grouping	**Density Range***	**Metals**
Very High Density	12 to 22	Gold, Iridium, Osmium, Palladium, Platinum, Rhodium, Ruthenium, Tantalum, Tungsten, Uranium (depleted)
High Density	9.8 to 11.9	Bismuth, Lead, Molybdenum, Silver
Average Density	6 to 9.7	Antimony, Cadmium, Cast Iron, Copper alloys, Nickel, Nickel alloys, Stainless steels, Steels, Tin, Zinc
Low Density	1 to 5.9	Aluminum, Aluminum alloys, Beryllium, Beryllium alloys, Magnesium, Magnesium alloys, Titanium, Titanium alloys

* (g/cm^3)

SPARK CHART



Metal	Stream Volume	Relative Length*	Color of Stream	Color of Bursts	Quantity of Bursts	Nature of Bursts
1. Wrought Iron	Large	65	Straw	White	Very few	Forked
2. Machine Steel (AISI 1020)	Large	70	White	White	Few	Forked
3. Carbon Tool Steel	Moderately large	55	White	White	Very many	Fine, repeating
4. Gray Cast Iron	Small	25	Red	Straw	Many	Fine, repeating
5. White Cast Iron	Very small	20	Red	Straw	Few	Fine, repeating
6. Annealed Mall. Iron	Moderate	30	Red	Straw	Many	Fine, repeating
7. High-Speed Steel (18-4-1)	Small	60	Red	Straw	Extremely few	Forked
8. Austenitic Manganese Steel	Moderately large	45	White	White	Many	Fine, repeating
9. Stainless Steel (Type 410)	Moderate	50	Straw	White	Moderate	Forked
10. Tungsten-Chromium Die Steel	Small	35	Red	Straw†	Many	Fine, repeating†
11. Nitrided Nitralloy	Large (curved)	55	White	White	Moderate	Forked
12. Stellite®	Very small	10	Orange	Orange	None	
13. Cemented Tungsten Carbide	Extremely small	2	Light Orange	Light Orange	None	
14. Nickel	Very small‡	10	Orange	Orange	None	
15. Copper, Brass, and Aluminum	None				None	

* actual length varies with grinding wheel, pressure, etc.
† blue-white spurts
‡ some wavy streaks

Figure 38-13. *Spark charts are compared with spark stream characteristics to identify unknown metals.*

Spark testing heat treats the surface layer of the metal, leading to localized hardening and possible cracking. Stock is discarded any closer than ¼″ from the area of contact with the grinding wheel because of possible failure.

Spark Test Preparation. The area of metal selected for spark testing must be free of scale and representative of the chemical composition of the metal. Before conducting a spark test, the grinding wheel is cleaned with a diamond wheel dresser to remove particles of metal from previous tests. If these particles are not removed, the spark stream of the specimen being examined would be contaminated by sparks from previous tests.

Small, portable grinders are most often used for spark testing, because they can be transported to the field. Stationary grinders may be used if convenient. See Figure 38-14.

The pressure between the grinding wheel and the specimen must be sufficient to maintain steady contact. The spark stream should be given off approximately 1 ft horizontally and at right angles to the line of vision. The tester must have a clear, unobstructed view of the spark stream. Conditions for spark testing must be standardized and testing should be conducted in diffuse daylight, not bright sunlight or darkness. The spark should be tested away from air drafts that may cause the tail of the spark stream to hook, which leads to an erroneous interpretation.

Grinding Wheel Rotation. The speed of the wheel in feet per minute (fpm) equals the circumference in inches multiplied by the revolutions per minute at which the wheel turns, divided by 12. To provide a satisfactory spark stream, the grinding wheel must rotate at high speeds (15,000 fpm or greater) and must be hard (for example, 40 grain alumina wheel).

Figuring wheel rotation. Is a rotation speed of 16,000 rpm suitable for a 2″ diameter portable grinder?

$$C = \pi d$$

where

C = Circumference of wheel

π = pi (3.142)

d = diameter

$$C = 3.142 \times 2$$

$$C = \mathbf{6.248''}$$

$$S = \frac{C \times R}{12}$$

where

S = Speed of wheel (in fpm)

C = Circumference of wheel (in in.)

R = Rotation speed (rpm)

12 = constant

$$S = \frac{6.284 \times 16{,}000}{12}$$

$$S = \frac{100{,}544}{12}$$

$$S = \mathbf{8378.6\ fpm}$$

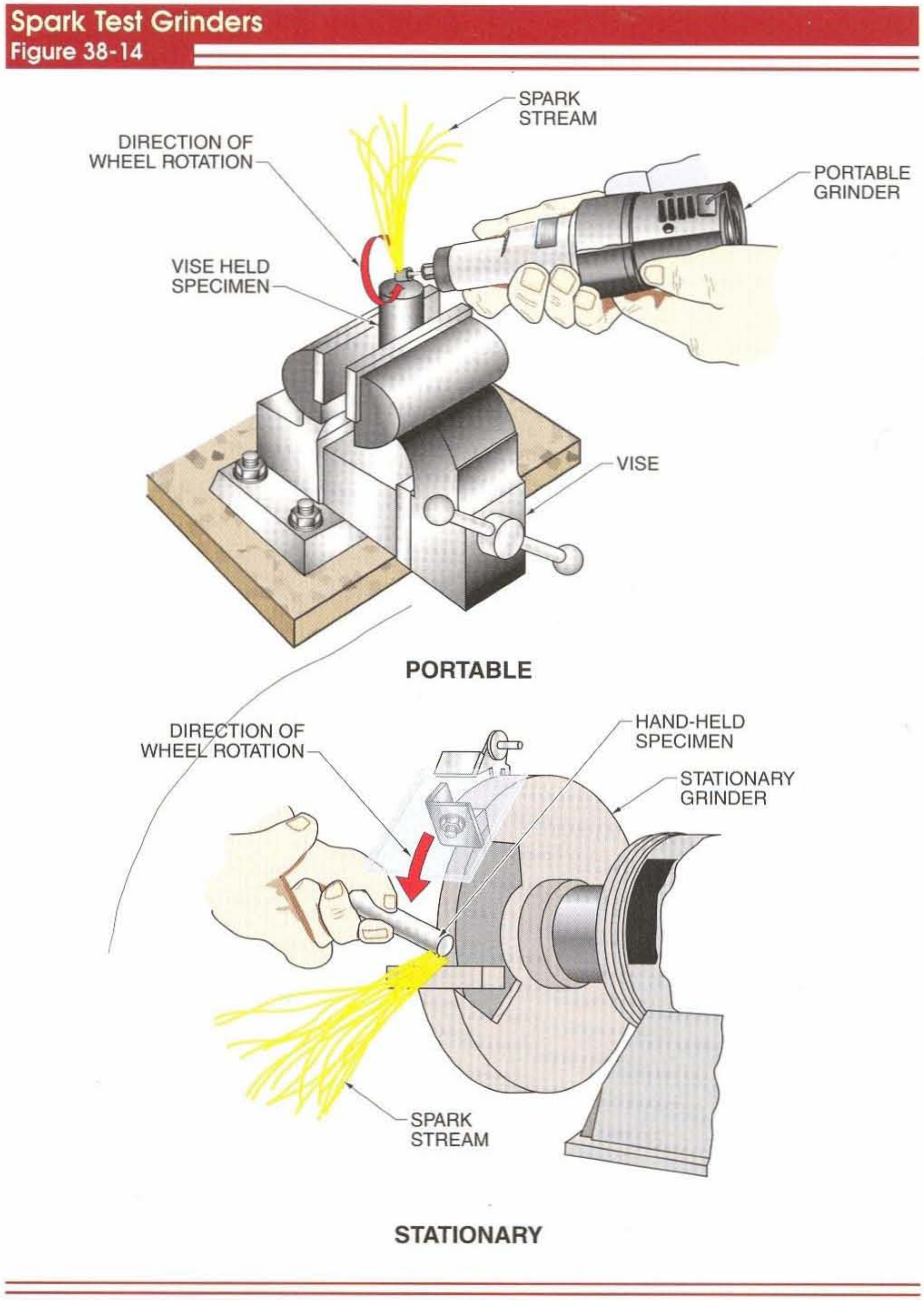
The wheel rotation speed is not suitable for spark testing.

⚠ WARNING

Protective goggles and protective clothing must be worn when spark testing.

A grinding wheel is used for spark testing and should be kept clean to prevent contaminants from interfering with the spark stream.

Figure 38-14. *Spark testing is most often performed using portable grinders, but stationary grinders may also be used.*



Spark Stream Identification. The spark stream must be closely examined for its characteristic features. Characteristic features include carrier lines, forks, bursts, and arrowheads. A *carrier line* is an incandescent (glowing) streak that traces the trajectory (path) of each particle (spark). A *fork* is a simple branching of the carrier line. A *burst* is a complex branching of the carrier line. An *arrowhead* is a termination of the carrier line in the shape of an arrowhead. See Figure 38-15.

By learning to identify the different portions of the spark stream, and by making tests on known samples, it is possible to acquire sufficient experience to make relatively accurate determination of the metal being investigated.

Spark Test Identification
Figure 38-15

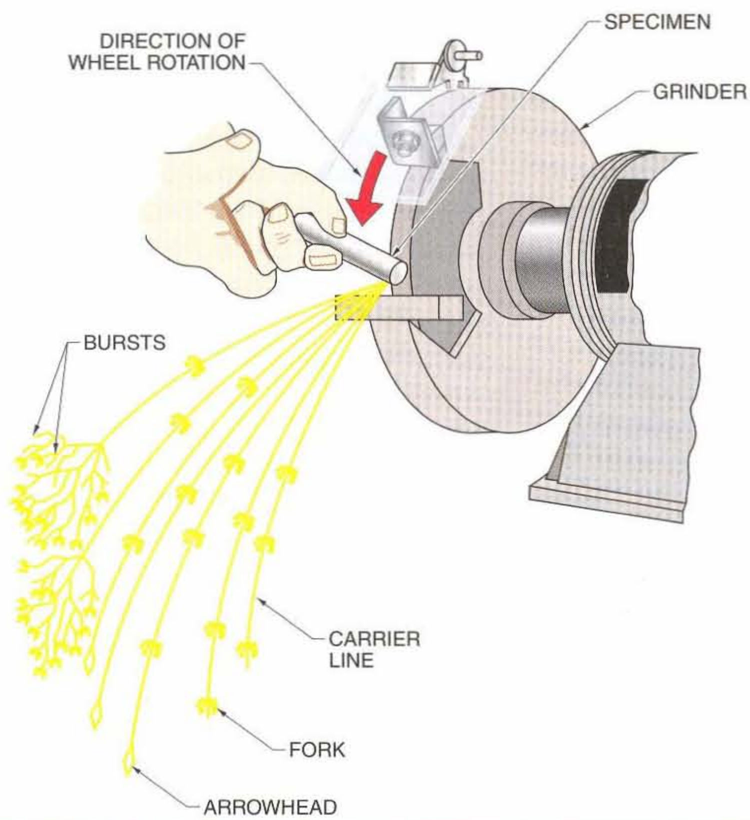


Figure 38-15. *Characteristic features of spark streams include carrier lines, forks, bursts, and arrowheads.*

Some reagents used in chemical spot testing kits are strong acids or alkalis and should be handled with care.

Chemical Spot Testing

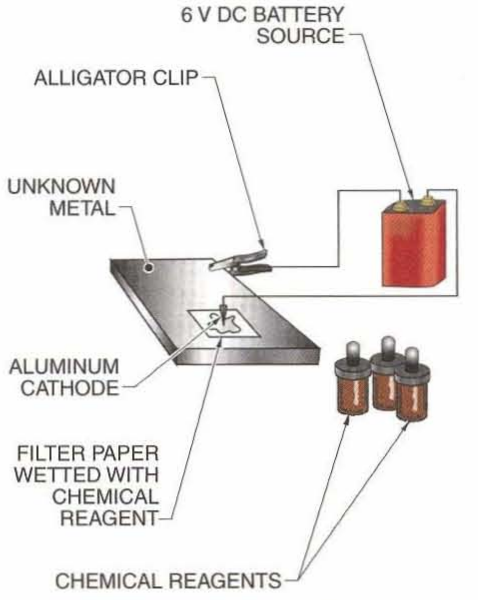
Chemical spot testing is a semi-quantitative identification method that uses chemicals that react when placed on certain types of metals. Chemical spot testing is used to identify metals by the color changes that occur to the metal when a metal is contacted with specific chemical reagents.

The solution is often produced using electric current (electrographic technique) to dissolve small amounts of the metal in a chemical reagent. When the solution reacts with the chemical reagent, a color change occurs, which is used to identify the unknown metal.

The most common chemical spot test is the electrographic chemical spot test. In electrographic chemical spot testing, a metal surface is first prepared by dressing it with a file or emery paper to remove scale or unnecessary roughness, after which the metal surface is degreased. A filter paper wetted with measured drops of chemical reagent is placed on the metal surface. The unknown metal (anode) is electrically connected to the positive terminal of a 6 VDC battery. An aluminum cathode, connected to the negative terminal of the battery, is pressed against the wet filter paper. This connection completes the electrical circuit and allows current to flow until the cathode is removed and the circuit is disconnected. See Figure 38-16.

Figure 38-16. *The electrographic chemical spot test is the most commonly used chemical spot test.*

Electrographic Chemical Spot Test
Figure 38-16



The filter paper, which is soaked in a small amount of the metal solution, is lifted from the surface. Measured drops of a second chemical reagent are applied to the wet filter paper, causing a color change. The color of the filter paper identifies the metal. Supplementary reagents may be applied to the filter paper to cause additional color changes, which further identify the metal. When the test is complete, the metal surface is thoroughly cleaned to remove excess chemical reagent.

⚠ WARNING

Avoid accidental contact with hot metal surfaces during thermoelectric potential sorting.

Thermoelectric Potential Sorting

Thermoelectric potential sorting is a semi-quantitative identification method that uses measurement of the electric potential generated when two metals are heated. The common and reproducible method of thermoelectric potential sorting is to standardize on the voltage generated by the heated junction of two dissimilar metals. Standardizing on the voltage generated by the junction of the two metals allows a significantly greater amount of heat to be generated, which increases sensitivity. To carry out identification, the unknown metal is put in contact with a heated probe. The thermoelectric potential generated is indicated on a digital or analog readout. This value of thermoelectric potential is compared with values obtained under identical conditions using known metal samples. Thermoelectric potential sorting is described in ASTM E977, *Standard Practice for Thermoelectric Metal Sorting.*

Null Point Method. The *null point method* is an alternative method of thermoelectric potential sorting. The null point method is used for identifying an unknown metal or distinguishing it from other metals. In the null point method, a known standard specimen and a probe are electrically connected and the deflection of the meter caused by the resulting potential is recorded. The resulting potential is calibrated to read zero on a meter.

An unknown metal that is the same as the known specimen will produce no deflection of the meter. If the unknown metal is different from the known specimen, the meter will deflect to either side of zero.

Electrical Resistivity Testing

Electrical resistivity testing is a semi-quantitative identification method that uses differences in electrical resistivity to identify metals. With electrical resistivity testing, a small probe containing four electrodes is placed on the metal surface and an electric current is passed through the metal. The current passing through the metal causes a number to register on the panel of the instrument. This number (ohms) is a measure of the resistivity of the unidentified metal. The surface must be prepared with a file if it is excessively rough or corroded.

For materials over .1″ thick, the instrument is self-compensating. For materials less than .1″ thick, the tester must apply a correction factor based on the metal thickness. The instrument is also sensitive to the area of metal beneath the probe. Two differing measurements may be displayed on different parts of a component exhibiting different thicknesses, such as a casting. The tester must calibrate the instrument readings against known metal samples to prevent misinterpretation of the data.

The electrical resistivity method provides rapid metal sorting or identification. The relatively small probe head of the electrical resistivity instrument allows it to be used for examining hard to reach areas such as the internal components of valves.

Optical Emission Spectroscopy

Optical emission spectroscopy is a semiquantitative identification method that separates and analyzes the light emitted from an unknown metal surface when it is arced by an electric current. An *optical emission spectrometer* is an instrument used for optical emission spectroscopy that is placed on the surface of an unknown metal. A small area of the surface is intermittently sparked by striking an arc between the surface and a tungsten electrode using a power source of 25 V to 40 V. When the electric arc is struck on a metal surface, the light emitted is composed of various wavelengths. The chemical elements in the metal determine the component wavelengths produced. The intensity of each component wavelength is proportional to the concentration of its corresponding chemical element. See Figure 38-17.

All light emitted from the arc is passed through a glass prism, which diffracts it into its component wavelengths. *Diffraction* is a modification of light in which the rays appear to be deflected to produce fringes of parallel light and dark colored bands. The separated wavelengths are viewed as a series of lines of varying intensity and color.

Optical Emission Spectroscopy
Figure 38-17

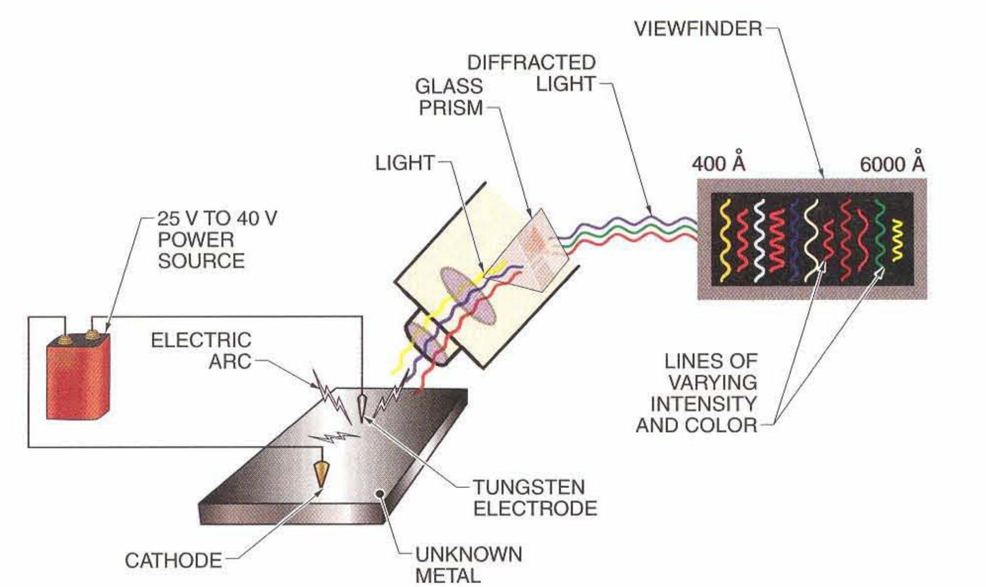


Figure 38-17. *Optical emission spectroscopy uses the light emitted from unknown metal surfaces to identify a metal.*

The wavelength lines are compared with those obtained from standard elements. A camera that is connected to the eyepiece of the optical emission spectrometer permanently records the lines. The camera improves the sensitivity of the instrument because it records lines that are too faint for detection by the human eye. The camera also records the lines from the ultraviolet spectrum.

The chemical elements detectable by optical emission spectroscopy are limited to those elements that have observable light wavelengths after diffraction and are not vaporized by the heat of the arc. Low percentages of chemical elements may be undetected if the line obtained by diffraction is faint. Optical emission spectroscopy can detect nickel, chromium, molybdenum, titanium, manganese, vanadium, copper, zinc, tungsten, magnesium, cobalt, lead, and niobium.

QUANTITATIVE IDENTIFICATION

Quantitative identification methods separate and identify metals by measuring the amounts of chemical elements present in a metal.

Quantitative identification methods separate and identify metals by measuring the amounts of chemical elements present in a metal. Although quantitative identification methods do not analyze for every chemical element that may be present, they are often comprehensive enough to identify unknown metals with a high degree of accuracy.

Nondestructive quantitative identification instruments are more costly than semi-quantitative identification instruments. However, printed reports may be obtained and data archived to provide documentation required in a formal quality assurance program. Quantitative identification methods include X-ray fluorescence spectrography and chemical analysis.

Radiation detection devices should be used as required to monitor radiation levels when performing X-ray fluorescence procedures.

X-Ray Fluorescence Spectrography (XRF)

X-ray fluorescence spectrography (XRF) is a nondestructive quantitative identification method that uses a gamma ray beam to identify an unknown metal. The beam causes the atoms of specific chemical elements in the metal to fluoresce, or exhibit fluorescent X-rays. Fluorescent X-rays have energy levels that are characteristic of the specific chemical elements in the unknown metal. The fluorescent characteristic X-rays are passed through a detector that measures energy levels and the chemical composition. See Figure 38-18.

The probe of the instrument is placed on the unknown metal. A shutter in the probe is opened for a specific length of time to allow gamma rays from the source (such as iron-55 isotope) to be beamed onto the unknown metal. A microprocessor built into the instrument displays the percentages of the chemical elements present in the unknown metal. The microprocessor is also programmed to display the names of specific alloys when the analysis of the unknown metal matches the chemical composition of the known metal. The instrument is portable and easily moved to the component to be analyzed. Within minutes, the instrument can provide quantitative analysis of the indicated chemical composition.

If the surface upon which the probe is placed is not flat or does not fully cover the specimen, a compensation factor must be applied. This is because curvature, surface irregularities, or the small size of the contact area causes the excitation beam to miss part of the surface, resulting in lower than expected readings. Small sections of metal such as filler metal must be cut into small pieces and banded together to provide an adequate cross-sectional area for the probe.

X-ray Fluorescence Spectrography
Figure 38-18

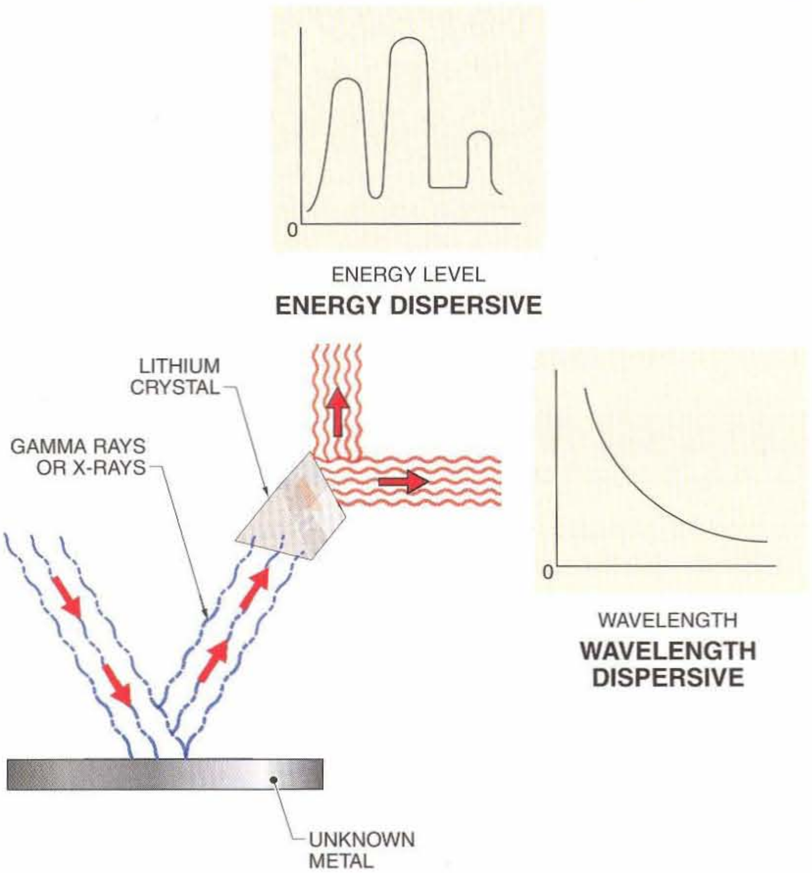


Figure 38-18. *X-ray fluorescence spectrography uses a detector that separates and identifies energy levels or energy wavelengths.*

The X-ray fluorescence instrument must be standardized regularly to allow for radioactive decay of the radioisotope. Radioactive decay results in a decrease in emission and a correspondingly lower fluorescent X-ray count. Standardization is carried out by calibrating on a metal sample of known composition.

The X-ray fluorescence spectrography method measures the percentages of titanium, vanadium, chromium, manganese, iron, cobalt, nickel, copper, niobium, molybdenum, and tungsten in a metal. A major limitation of X-ray fluorescence spectrography, as with all techniques, is that it cannot measure carbon percentage. Thus, it cannot distinguish between various carbon steels and low-carbon or regular grade austenitic stainless steels. Chemical analysis must be used to measure carbon.

Chemical Analysis

Chemical analysis is a destructive quantitative identification method that requires removal of a small sample (1 g to 2 g) of metal for chemical analysis of its constituent elements. Chemical analysis is destructive and time-consuming and is used when auditing of a product is required or the analysis must be checked against a materials test report (MTR). Wet chemical analysis is the only method of obtaining the amount of carbon present in an alloy.

⚠ WARNING

Adequate precautions against exposure to radiation must be taken when using X-ray fluorescence equipment.

Filler metals are identified by paper labels or identification markings stamped on one end of the filler metal.

Filler Metal Identification

Welding filler metals (wire or rod) and electrodes use a mixture of marking systems. Filler metal and electrodes are identified by markings that are attached, stamped, or stenciled on filler metals. Identification markings on bare wire usually consist of the AWS designation printed on a paper tag glued to one or both ends of the wire. On large-diameter nonferrous filler metal, identification markings are stamped on the filler metal. Identification markings on covered electrodes consist of the AWS designation stenciled on the flux coating at one end of the filler metal. In all cases, additional identification is provided on a label attached to the container or spool holding the electrode or filler metal.

Some marking products may be potentially harmful to metals. Care must be taken to identify harmful marking products and thoroughly remove them before welding, brazing, or soldering.

POINTS TO REMEMBER

1. Manufacturers supply three types of paperwork to identify their products: materials test report, product analysis, and certificate of compliance.
2. A materials nonconformance report helps the end user document problems in received materials so that problem areas can be identified, corrected, and prevented in the future.
3. Visual identification includes appearance, color, nameplate, and markings to determine key features that identify the metal type.
4. Magnetic force is categorized as strong attraction, weak attraction, or no attraction. The category of magnetic response allows the unknown metal to be placed into a specific identification grouping.
5. Semi-quantitative identification methods use a physical stimulus to provide a signal that may be compared with a set of standards. Semi-quantitative identification methods include density testing, spark testing, chemical spot testing, thermoelectric potential sorting, and optical emission spectroscopy.
6. Metals are categorized as one of four density groupings, very high density, high density, average density, and low density, based on their figured density value.
7. Quantitative identification methods separate and identify metals by measuring the amounts of chemical elements present in a metal.
8. Filler metals are identified by paper labels or identification markings stamped on one end of the filler metal.

QUESTIONS FOR STUDY AND DISCUSSION

1. What type of information is contained in an MTR?
2. What is a certificate of compliance (COC)?
3. When should visual identification by color not be used?
4. What information is included in a foundry marking?
5. What change in the welding process can affect the magnetic response of metals?
6. Metal can be placed into which four density groupings?
7. What are the four primary characteristics of a spark stream?
8. What is the most common type of chemical spot test?
9. What is an important element that X-ray fluorescence spectrography (XRF) fails to detect?
10. How are welding filler metals identified?

39 Weldability of Carbon & Alloy Steels

Weldability is the capacity of a metal to be welded, under imposed fabrication conditions, into a specific, suitably designed structure that performs satisfactorily in the intended service. Carbon is the principal alloying element that effects the weldability of carbon steels. Alloying elements also have an effect on preheat and postheating in alloy steels. Factors that affect the weldability of carbon and alloy steels must be considered to ensure the desired quality during fabrication.

CARBON AND ALLOY STEELS

Steels are broadly classified as carbon steels or alloy steels based on their alloying elements. Carbon steels are alloys of iron, carbon, and manganese. Carbon is the principal alloying element that affects the mechanical properties and metallurgical structure of carbon steels. Carbon steels are grouped according to their carbon content and include low-carbon steels, medium-carbon steels, and high-carbon steels. Free-machining steels are an additional group. See Figure 39-1. The weldability of carbon steels decreases as the carbon content increases.

Low-carbon steels contain up to .3% carbon and up to 1.2% manganese. They are not strengthened by heat treatment but may be surface hardened by carburizing. Low-carbon steels are used for structural applications such as building framework, pressure vessels, and automobile bodies.

Nickel steels are low-carbon steels that contain 2% to 9% nickel for service at low temperatures for applications from 32°F (0°C) to –320°F (–195°C). Nickel steels are used for storage tanks for liquefied hydrocarbon gases and machinery designed for use in cold climates.

Medium-carbon steels contain .3% to .6% carbon and .6% to 1.65% manganese. Medium-carbon steels are stronger than low-carbon steels. They form high hardness martensite in the HAZ when rapidly cooled and are susceptible to hydrogen cracking. They may require heat treatment after welding to achieve the specified strength and hardness. Wear resistance may be improved by surface treatments such as chrome plating or nitriding. The surface coating must be removed by grinding if any weld repair is to be performed. Medium-carbon steels are used in machinery parts such as tractors, derricks, and pumps.

High-carbon steels contain more than .6% carbon. High-carbon steels are usually not welded. They are used for their hardness and strength, especially where a cutting edge is required, such as on drill bits and files.

Carbon steels include low-carbon steels, medium-carbon steels, and high-carbon steels. The weldability of carbon steels decreases as the carbon content increases.

Carbon Steel Alloy Families
Figure 39-1

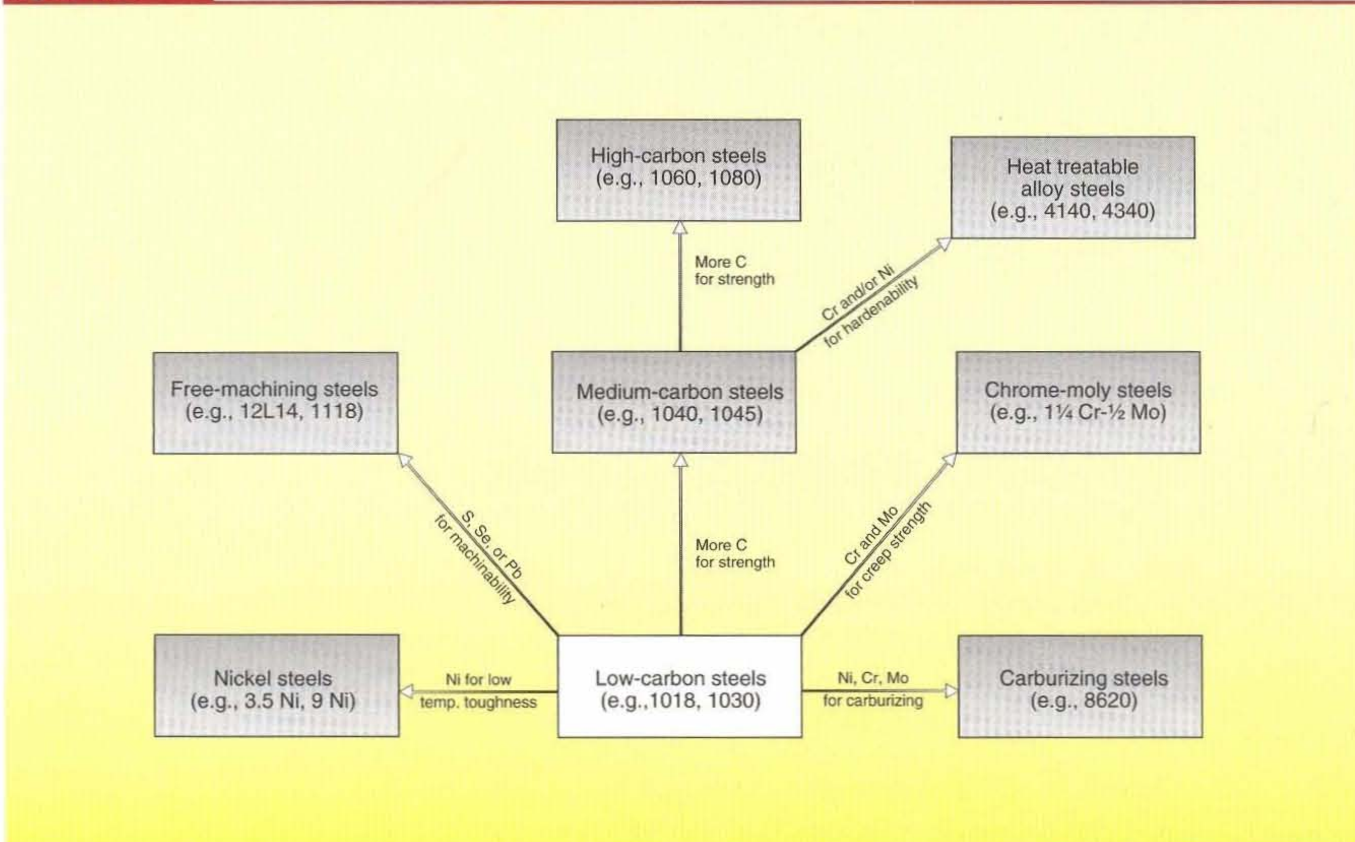


Figure 39-1. *Carbon steels are grouped by their carbon content into low-carbon, medium-carbon, high-carbon, and free-machining steels.*

Free-machining steels are low-carbon steels that contain small amounts of sulfur, phosphorus, or lead, which are added to improve their machinability. Free-machining steels are used where high production machining is required.

Alloy steels contain specified quantities of alloying elements other than carbon and manganese. Alloy steels are grouped according to their alloying elements. The presence of one or more alloying elements in alloy steels leads to better mechanical properties than carbon steels. The principal benefits of alloy steels over carbon steels are higher strength and greater capacity for strengthening in thick sections (hardenability). Alloy steels consist of low-alloy steels, chrome-moly steels, and austenitic manganese steels.

The principal benefits of alloy steels over carbon steels are higher strength and greater capacity for strengthening in thick sections (hardenability).

Low-alloy steels are medium-carbon steels that contain small percentages of nickel, chromium, and molybdenum to achieve optimum mechanical properties in the quenched and tempered condition. The wear resistance of low-alloy steels may be improved by surface treatments such as chrome plating or nitriding. The hardened surface coating must be removed by grinding if any weld repair is to be performed. Low-alloy steels are used for mechanical components such as shafts and machinery where high strength and toughness are required, particularly where the section thickness exceeds 2″.

Chrome-moly steels contain approximately .2% carbon, .5% to 9% chromium (Cr), and .5% to 1% molybdenum (Mo). Scaling resistance increases as the chromium content is increased. Molybdenum increases strength at elevated temperatures and provides resistance to graphitization. *Graphitization* is the formation of iron carbide that results in loss of ductility. The carbon content of

chrome-moly steels is kept below .2% to maintain weldability. Chrome-moly steels are widely used for piping and vessels operating at temperatures up to 1000°F (537°C) in the petroleum refining industry and in steam power generation. Chrome-moly steels are identified by their nominal percentages of chromium and molybdenum, for example 1¼Cr-½Mo, or 2¼Cr-1Mo. See Appendix.

Austenitic manganese steels contain 11% to 14% manganese and .7% to 1.4% carbon. Austenitic manganese steels are nonmagnetic alloy steels noted for high strength, excellent ductility, toughness, and outstanding wear resistance. Austenitic manganese steels are used for crushing, earth-moving, and material handling equipment; railroad track parts; and electrical equipment where nonmagnetic properties are important.

Steel Deoxidation

Steel deoxidation is the process of removing a controlled amount of oxygen from steel during steelmaking. The deoxidation practice determines the amount of deoxidation performed and the basic steel type that is produced. Steel deoxidation results in four types of steel: killed, semikilled, rimmed, and capped. See Figure 39-2.

Killed steel is steel that is completely deoxidized during steel production by adding silicon or aluminum in the furnace ladle or to the mold. Aluminum and silicon cause the steel to solidify quietly and suppress (kill) the gas evolution that would result from combining carbon and oxygen and forming carbon monoxide. Killed steel is homogeneous, has a smooth surface, and contains no blowholes. Killed steels are commonly used where improved strength and toughness are important.

Semikilled steel is steel in which deoxidizers only partially kill the oxygen-carbon reaction. Semikilled steel is more uniform in composition throughout the cross section and is suitable for applications involving carburizing and heat treating.

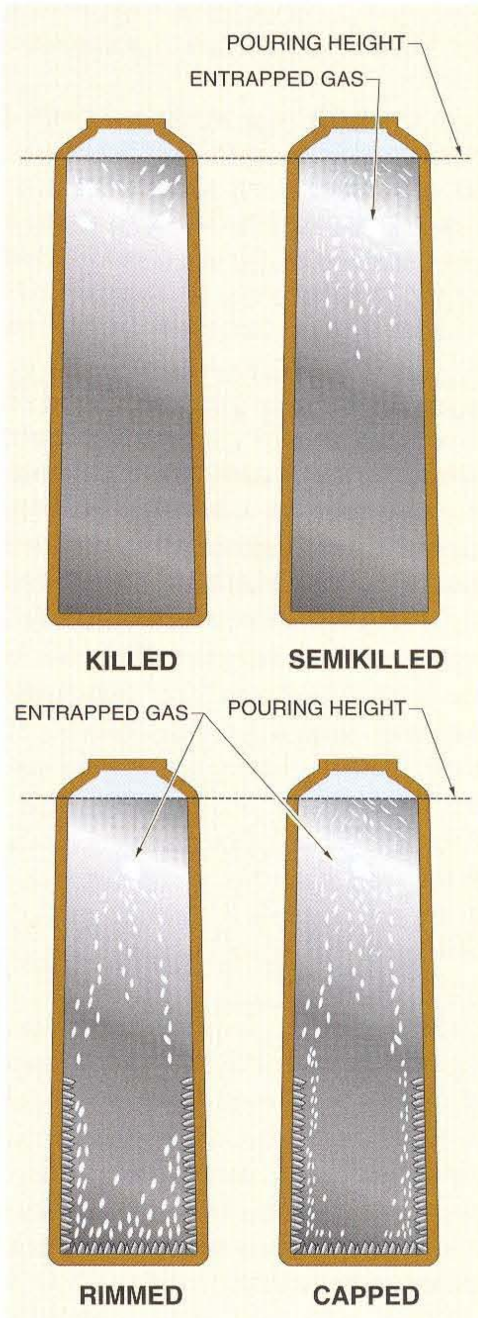


Figure 39-2. *The steel deoxidation practice influences the type of steel produced.*

The deoxidation practice determines the amount of deoxidation performed and the basic steel type produced.

Rimmed steel is steel with little or no deoxidizer addition. The molten metal briskly bubbles as oxygen evolves from it when it is poured into a mold. The evolving oxygen reacts with the carbon at the boundary between the solidified metal adjacent to the mold and the remaining molten

metal, forming carbon monoxide gas. This reaction causes the outer rim of the solidified metal to be very low in carbon and, consequently, very ductile. Rimmed steel may be rolled to produce a very sound surface and is used for sheet products such as automobile bodies.

Capped steel is a variation of rimmed steel, providing a surface condition similar to rimmed steel, but other properties are intermediate between rimmed steel and semikilled steel.

General Welding Considerations for Carbon and Alloy Steels

When steels are welded, the rapid cooling rate from the welding temperature causes a metallurgical transformation similar to that which occurs in quenching during heat treatment. This transformation results in martensite formation in the HAZ. The hardness of martensite increases with the carbon content of steel, reducing toughness and increasing susceptibility to cold cracking (hydrogen cracking) from residual stress in the weld joint. Martensite that forms in low-carbon steels is generally too soft and ductile to cause embrittlement or cracking.

Hydrogen cracking is often located below the surface and may not be detected by common nondestructive examination techniques.

Steels that are susceptible to cracking must be preheated to reduce the rate of cooling and decrease the possibility of martensite formation. Postheating is used to improve the toughness of any martensite that does form by tempering it to reduce (relieve) residual stress and eliminate hydrogen.

Steels that are susceptible to cracking must be preheated to reduce the rate of cooling and decrease the possibility of martensite formation.

Alloy steels form either martensite or bainite as they cool, depending on the cooling rate. Bainite is not as brittle as martensite and forms at a slower cooling rate. A high preheat temperature is used to slow the cooling rate of alloy steels to form bainite rather than martensite. Bainite is less likely to crack than martensite, allowing time for postheating to be performed.

Hydrogen Cracking. Hydrogen cracking is caused by atomic hydrogen that may be present on carbon and alloy steels. Sources of atomic hydrogen are organic material such as grease; chemically bonded or absorbed water in the electrode coating; and moisture on the steel surface at the weld location.

Atomic hydrogen is created at welding temperature and diffuses rapidly into molten weld metal. As the weld metal solidifies, the hydrogen tries to escape because solidified metal accommodates significantly less hydrogen than liquid metal. Some hydrogen escapes into the atmosphere; however, some hydrogen escapes into the HAZ.

Martensite formed in the HAZ by rapid cooling of the weld is extremely susceptible to embrittlement from the hydrogen that escapes into it. Hydrogen cracking occurs when the brittle martensite fails to yield (stretch) to accommodate the residual stresses that develop as the weld cools. Hydrogen cracking may occur several days after the weld has cooled. Hydrogen cracking is often located below the surface and may not be detected by common nondestructive examination techniques. See Figure 39-3. Methods of preventing hydrogen cracking are:

- using low-hydrogen electrodes and storing electrodes in a low-temperature oven
- heating surface before welding to remove moisture
- postheating immediately after welding to drive out hydrogen

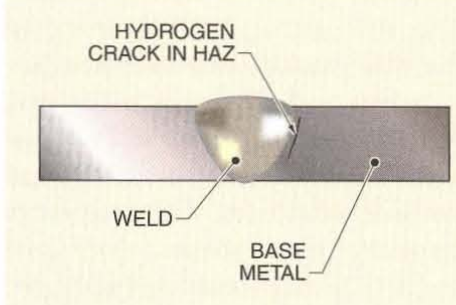


Figure 39-3. *Hydrogen cracking may not be detected by nondestructive examination because it commonly occurs below the surface.*

> Steels with a low carbon equivalent typically have excellent weldability. As the carbon equivalent rises above .4, the susceptibility to underbead cracking increases.

Carbon Equivalent. *Carbon equivalent* is a formula based on the chemical composition of a steel, which provides a numerical value to indicate whether preheat and postheating are required. The greater the numerical value of carbon equivalent, the greater the tendency for cold cracking and the greater the need for preheat and postheating.

Carbon is the most significant alloying element that is added to iron in steels, contributing to overall strength and hardness. Other alloying elements contribute to hardness, but to a lesser extent than carbon. The carbon equivalent is the sum of the carbon percentage, plus the weighted percentages of each alloying element on martensite formation. With carbon steels, manganese is the only other element whose influence is weighted. For alloy steels, the weightings of individual alloying elements are added. The higher the carbon equivalent, the greater the need for preheat and postheating to prevent embrittlement by martensite.

To find the carbon equivalent for carbon steels, apply the formula:

$$CE = C + \frac{Mn}{6}$$

where

CE = carbon equivalent

C = percent carbon

Mn = percent manganese

6 = constant

For example, what is the carbon equivalent of a steel that contains .28% C and .7% Mn?

$$CE = \%C + \frac{\%Mn}{6}$$

$$CE = .28 + \frac{.7}{6}$$

$$CE = .28 + .12$$

$$CE = \mathbf{.4\%}$$

Carbon steel with a carbon equivalent less than .4% is weldable without preheat or postheating, depending on joint member thickness. For alloy steels, the carbon equivalent is found by applying the formula:

$$CE = \%C + \frac{\%Mn}{6} + \frac{\%Ni}{20} + \frac{\%Cr}{10} + \frac{\%Cu}{40} - \frac{\%Mo}{50} - \frac{\%V}{10}$$

Joint Member Thickness. Joint member thickness also influences preheat. With increasing joint member thickness, the preheat temperature must be increased to reduce the cooling rate and the tendency to form martensite. Since the ductility of martensite depends on its hardness, which is a function of the carbon content of the steel, the formula for calculating preheat is based upon the thickness of the steel and its carbon content:

$$P = 1000\,(C - .11) + 18t$$

where

P = preheat temperature (in degrees Fahrenheit)

C = carbon content of steel

t = thickness of joint (in inches)

For example, what is the preheat temperature for a joint 2″ thick made of steel containing .35% carbon?

$$P = 1000\,(.35 - .11) + 18(2)$$

$$P = 1000 \times .24 + 36$$

$$P = 240 + 36$$

$$P = \mathbf{276°F}$$

As a rule, preheat is usually unnecessary for steels with a carbon content less than .2% if the joint thickness is less than:

- 1½″, for wrought pressure vessel plate
- ¾″, for wrought pipe
- ½″, for castings

However, the weld area should always be heated to hand warmth before welding.

Heat Requirements. Heat requirements include preheat, interpass temperature control, and postheating. Preheat heats

the base metal to a relatively low temperature before welding starts. The main purpose of preheat is to lower the cooling rate of the weld, thus allowing slower withdrawal of heat from the weld area, which lessens the tendency for martensite to form. Consequently, there is less likelihood for a hard zone to develop in the surrounding weld area than if a weld joint is made without preheat.

Preheat prevents cold cracks, reduces hardness in the HAZ, reduces residual stresses, and reduces distortion. Preheat also burns grease, oil, and scale out of the joint, ensuring a clean welding surface and allowing a more rapid welding speed. Preheat can be accomplished by moving an oxyacetylene flame over the surface or by placing the part in a heating furnace. See Figure 39-4. Preheat temperatures for carbon steel range from 200°F (93°C) to 700°F (371°C), depending on the carbon content. The greater the carbon content, the higher the preheat temperature.

Temperature must be maintained between the minimum and maximum interpass temperatures for each succeeding welding pass.

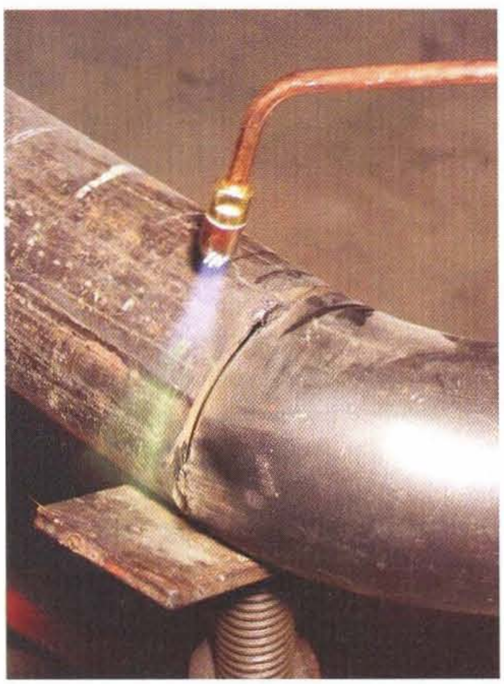


Figure 39-4. *A common preheat method is to move an oxyacetylene flame over the surface of the metal.*

The interpass temperature is the temperature of the weld area between passes of a multiple-pass weld. For most steels, the large volume of heat produced by the welding process is often a more economical method of maintaining interpass temperature. Using a high current and slow travel rate causes considerable heat to build up in the metal, slowing the rate of cooling after welding and preventing martensite from forming near the weld area.

In multiple-pass welding, the first pass preheats the base metal. Heat from the second pass tempers the base metal adjacent to the first pass. Each successive pass produces enough heat to prevent hardening caused by rapid cooling. The interpass temperature must be carefully regulated. Minimum and maximum interpass temperatures are generally specified for multiple-pass welds. Temperature must be maintained between the minimum and maximum interpass temperatures for each succeeding welding pass. On small parts, the temperature during welding can increase to undesirable levels. A welder must allow time for the workpiece to cool between weld passes.

Postheating is a stress-relief treatment for welding medium- and high-carbon steels. Postheating is as important as preheat. Although preheat controls the cooling rate, the possibility of stresses being locked into the weld area is always a factor. Postheating is especially necessary for thick metal or when the part is restrained in a jig or fixture during welding. Unless stresses are removed, cracks may develop, or the part may become distorted when it cools completely, especially during machining operations.

Postheating temperatures for stress relief should be in the range of 900°F (482°C) to 1250°F (677°C). The postheating period normally runs about 1 hr per inch of metal thickness.

Specific Welding Considerations for Carbon and Alloy Steels

Factors influencing the welding of carbon steel depend upon the group to which the specific steel belongs.

Weldability decreases with increased carbon content, and the need for preheat and postheating increases with increased carbon content. See Figure 39-5.

Low-Carbon Steels. Low-carbon steels that contain less than .2% carbon and less than 1% manganese (carbon equivalent .36) are weldable without preheat or postheating when joint thickness is less than 1″ and joint restraint is not severe.

Low-carbon steels can be welded by arc welding and OFW processes. Low-carbon steels are the easiest to weld since no special welding preparations are necessary. For SMAW, E60XX filler metal is suitable provided there is sufficient weld metal in the joint to provide adequate strength. The choice of filler metal is determined by depth of penetration, type of current, position of the weld, joint design, and deposition rate. When slightly higher strength filler metal is desirable, or low-hydrogen filler metals are necessary, E70XX regular or E70XX low-hydrogen filler metals must be used. See Appendix.

When using GMAW or GTAW, filler metal selection depends on the deoxidation practice of the steel. Rimmed or capped steels create porous welds unless the filler metal contains deoxidizers. A suitable filler metal for these applications is ER70S-2. For killed or semikilled steels, in addition to ER70S-2, E70S-6 or E70S-7 filler metal may be used.

OFW requires steel filler metal that matches the strength of the base metal. Type R45 deposits low-carbon steel weld metal. Higher strength R60 is used to weld low-carbon steels with tensile strengths from 50 ksi to 65 ksi.

Medium-Carbon Steels. As the carbon content increases beyond .3% and the manganese content increases to 1.4% (carbon equivalent .53), susceptibility to hydrogen cracking increases so that welding with low-hydrogen filler metal is necessary. Nevertheless, steels containing about .3% carbon and a relatively low manganese content have good weldability. However, a pronounced change in weldability occurs when the carbon content is in the .3% to .5% range. As the carbon content of the steel is increased, the welding procedure must be altered to prevent the formation of hard martensite in the HAZ. The required preheat temperature increases as the carbon equivalent increases. With a carbon equivalent between .45% and .60%, a preheat temperature between 200°F (93°C) and 400°F (204°C) is required, depending on joint thickness. The interpass temperature should equal the preheat temperature. Postheating between 1100°F (593°C) and 1250°F (677°C) is recommended immediately after welding. If postheating is not possible, the temperature of the joint should be maintained after welding at slightly above the specified preheat temperature for 2 hr to 3 hr per inch of thickness to promote the diffusion of hydrogen into the base metal from the weld bead.

CARBON STEELS			
Steel	**Carbon Content**	**Weldability**	**Uses**
Low-Carbon	Up to .3%	Excellent	• Piping • Industrial Fabrication
Medium-Carbon	.3% to .6%	Fair	• Machine Parts
High-Carbon	.6% or Higher	Poor	• Railroad Track Lengths • Machine Dies

Figure 39-5. *Weldability decreases with increased carbon content, and the need for preheat and postheating increases with increased carbon content.*

Low-hydrogen filler metal should be used when welding medium-carbon steels.

Low-hydrogen filler metals with iron powder coatings usually minimize cracking when welding high-carbon steel.

Free-machining steels are not usually welded unless special precautions are taken.

Most medium-carbon steels are relatively easy to weld by arc and gas welding processes. For SMAW, E7018 or E7024 filler metal is frequently used because they have a high tensile strength and less tendency to produce underbead cracking, particularly when no preheat can be applied. However, medium-carbon steels must typically be preheated and/or postheated. E6012 or E6020 filler metal can also be used if precautions are taken and the cooling rate is sufficiently slowed to prevent excessive hardening of the weld.

For GTAW and GMAW, any of the ER70S-X series filler metals may be used if precautions are taken to prevent hydrogen entry into the weld from rusty or contaminated surfaces or from contaminated shielding gases. For OFW, a high-strength filler metal that matches the strength of the base metal, such as R60 or R65, should be used.

High-Carbon Steels. High-carbon steels are significantly more difficult to weld than other carbon steels and are not usually welded. They form hard martensite when quenched and are extremely sensitive to cracking. When high-carbon steels must be welded, high-strength filler metals in the E80XX, E90XX, or E100XX groups are preferred because they minimize underbead cracking. Preheat must also be used to prevent cracking. The postweld cooling rate must be kept as slow as possible.

ESAB Welding and Cutting Products

Filler metals used for welding carbon and alloy steels are selected based on the metal composition and the desired properties of the metal after welding.

Stainless steel filler metals such as the E310-15 type are frequently recommended for welding high-carbon steels because of their high ductility, provided weld strength is not an issue. Low-hydrogen filler metals with iron-powder coatings produce a ductile weld with minimum penetration.

Free-Machining Steels. Free-machining steels have poor weldability because they are susceptible to hot cracking from the formation of low-melting-point sulfur- and phosphorus-containing compounds. Lead in free-machining steels can melt during welding, emitting weld fumes and creating a health hazard. Lead may also cause porosity and embrittlement under certain welding conditions. Free-machining steels are not usually welded unless absolutely necessary.

Certain precautions must be taken if free-machining steels must be welded. For SMAW, low-hydrogen filler metals of the EXXX-18 group are used. For FCAW or GMAW, the same type of electrode as for the corresponding regular grade (non-free-machining) steel is used. GTAW is not normally used to weld free-machining steels. A low welding current is used to minimize dilution, porosity, and cracking; however, the low welding current leads to reduced welding speed. The work area must be adequately ventilated when welding free-machining steels that contain lead.

Low-Alloy Steels. Low-alloy steels are welded by arc welding and gas welding processes if they have been annealed or normalized. They are then quenched and tempered to achieve the desired properties. If quenching or tempering is not possible—for example, with complex parts where distortion might occur—preheat at 600°F (315°C) or higher is used. High preheat temperatures slow the cooling rate, allowing the formation of soft bainite rather than hard martensite, and permitting handling of the part between welding and postheating.

The recommended preheat temperature is about 50°F (28°C) above the temperature at which martensite begins to form on cooling. The preheat temperature may also be influenced by the thickness of the joint, alloy composition, and joint restraint.

Both preheat and postheating prevent weld cracks caused by shrinkage stresses. By reducing the rate of cooling, the stresses are distributed more evenly throughout the weld and released while the metal is still hot.

When the proper preheat temperature cannot be determined, the clip test can be used as a quick check. The clip test is not applicable to thin steels but produces good results on sections up to ⅜″ thick.

The clip test involves welding a piece of low-carbon steel to the steel workpiece that is being checked for preheat temperature. A convex fillet weld is made using an electrode and welding current similar to those required for the welding job. The weld is allowed to cool for 5 min and then the welder, wearing safety glasses, hammers the lug until it breaks off. If the lug breaks through the weld after a number of blows, the test indicates that no serious underbead cracking will result when welding is carried out in the same manner at normal room temperature. If the lug breaks and pulls out some of the base metal, the test indicates that the particular steel must be preheated. See Figure 39-6.

Low-alloy, high-strength filler metals E70XX, E80XX, E90XX, and E100XX are used for welding low-alloy, chrome-moly, and nickel steels when full strength is required. In addition to the standard symbols, low-alloy, high-strength steel filler metals carry a suffix in the form of a letter and a final digit. The letter indicates the chemical composition of the deposited metal. The final digit designates the exact composition of the broad chemical classifications. Low-alloy, high-strength steel arc welding filler metals are designated as E7010-Al, E8016-B2, etc. When welding any alloy steel, contact the filler metal manufacturer for proper filler metal selection.

The reaction of filler metals to heat treatment for alloy steels must match the reaction of the base metal. The carbon, phosphorus, and sulfur contents of the filler metal are generally maintained at low values to reduce hot cracking susceptibility and improve weld metal ductility. Filler metals with comparable composition but lower carbon content may be satisfactory where lower joint strength is acceptable.

The recommended preheat temperature for low-alloy steels is about 50°F (28°C) above the temperature at which martensite begins to form on cooling.

Before welding any alloy steel, check with the manufacturer for the proper filler metal.

Clip Test
Figure 39-6

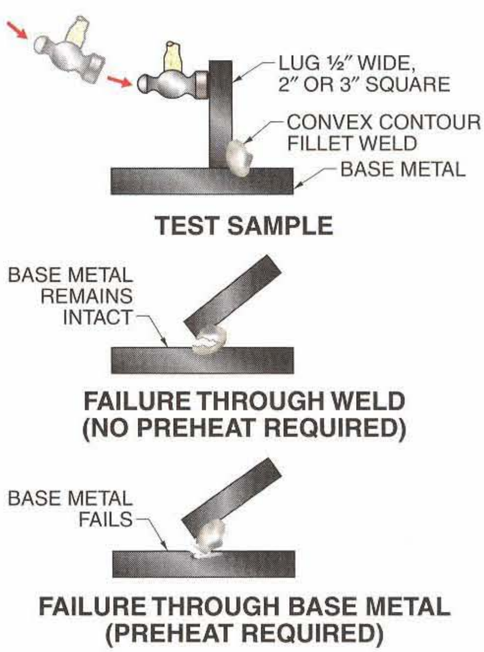


Figure 39-6. *The need for preheating may be indicated by the clip test.*

Chrome-Moly Steels. Chrome-moly steels are air-hardening and form martensite on cooling. The martensite is relatively soft because of the low carbon content, but all chrome-moly steels require preheat, interpass temperature control, and postheating to produce a tough weld joint. See Figure 39-7. Preheat and postheating temperatures vary depending on the alloy content of the

steel. Postheating for chrome-moly steels is usually completed immediately after welding.

Postheating temperatures for chrome-moly steels are higher than for carbon and low-alloy steels, because chrome-moly steels are more creep-resistant and require higher temperatures to cause them to yield. A postheating temperature of 1300°F (704°C) to 1350°F (732°C) is commonly used.

Chrome-moly steels may be joined by arc welding processes. A low welding current and rapid welding speed should be used, without extensive preheat. Care must be taken to prevent an excessive amount of base metal from mixing into the weld. Some preheat is advisable to reduce underbead cracking. Postheating is recommended for stress relief.

When an interrupted welding procedure is required—for example, to radiograph the partially completed joint in a heavy-wall pipe—the welding should not be interrupted until a distance equal to one-third the wall thickness has been welded, or not less than two weld passes for pipe less than 1″ thick. These precautions prevent cracking of the partially completed joint from residual stresses as it cools in order to be radiographed.

Filler metals must match the base metal composition, except that carbon content slightly lower than that of the base metal is needed to reduce cracking susceptibility. To limit the number of filler metals required when several chrome-moly steels are used on one job, filler metals of the same or slightly higher alloy content can be used. For example, 1¼ Cr-½ Mo filler metals can be used for welding ½ Cr-½ Mo and 1¼ Cr-½ Mo. For SMAW, low-hydrogen filler metals are used. See Figure 39-8.

Stainless steel filler metals E309 and E310 may be used for minor repair welding of chrome-moly steels. They are preferred for applications where the weld joint cannot be postheated. Stainless steel filler metals are weaker than chrome-moly electrodes and possess excellent as-welded ductility, yielding easily and relieving the majority of residual stresses. However, the selection of a stainless steel filler metal must be made carefully, especially if the weld joint is operating in cyclic temperature service where premature failure might occur.

Figure 39-7. *The required preheating temperature for chrome-moly steels varies according to the alloy content.*

RECOMMENDED PREHEAT TEMPERATURES FOR CHROME-MOLY STEELS*

Steel†	Thickness					
	Up to .5″ (13 mm)		.5″ to 1″ (13 mm to 25 mm)		Over 1″ (25 mm)	
	°F	°C	°F	°C	°F	°C
½Cr-½Mo	100	38	200	93	300	149
1Cr-½Mo	250	121	300	149	300	149
1¼Cr-½Mo						
2Cr-½Mo	300	149	350	177	350	177
2¼Cr-1Mo						
3Cr-1Mo						
5Cr-½Mo	350	177	400	204	400	204
7Cr-½Mo						
9Cr-1Mo						
9Cr-1Mo V+Nb+N						

* Welding with low-hydrogen covered electrodes

† Maximum carbon content of .15%. For higher carbon steels, preheat temperature should be increased 100°F to 200°F (38°C to 93°C). Lower preheat temperatures may be used with gas tungsten arc welding.

FILLER METALS FOR CHROME-MOLY STEELS*				
Chrome-Moly Content	GTAW[†] and GMAW	SMAW[‡]	FCAWS[§]	SAW[‖]
½Cr-½Mo	#	E801X-B1	E7XT5-A1 or E8XT1-A1	F8XX-EXXX-B1
1Cr-½Mo, 1¼Cr-½Mo	ER80X-B2 or ER70X-B2L	E801X-B2 or E701X-B2L	E8XTX-B2 or E8XTX-B2L or E8XTX-B2H	F8XX-EXXX-B2 or F8XX-EXXX-B2H
2¼Cr-1Mo	ER90X-B3 or ER80X-B3L	E901X-B3 or E801X-B3L	E9XTX-B3 or E9XTX-B3L or E9XTX-B3H	F9XX-EXXX-B3
3Cr-1Mo	**	**	**	**
5Cr-½Mo	ER502[††] or ER80X-B6	E502-1X[‡‡] or E801X-B6 or E801X-B6L	E502T-1 or 2 or E6XT5-B6	F9XX-EXXX-B6 or F9XX-EXXX-B6H
7Cr-½Mo	§§	E7Cr-1X[‡‡] or E801X-B7 or E801X-B7L	§§	§§
9Cr-1Mo	ER505[††] or ER80X-B8	E505-1X[‡‡] or E801X-B8 or E801X-B8L	E505T-1 or 2 or EX15-B8 or E6XT5-B8L	F9XX-EXXX-B8
9Cr-1Mo and V+Nb+N	ER90X-B9	E901X-B9	———	F9XX-EXXX-B9

* by welding process
† per ANSI/AWS A5.28, *Specification for Low-Alloy Steel Filler Metals for Gas Shielded Arc Welding* (unless indicated)
‡ per ANSI/AWS A5.5, *Specification for Low-Alloy Steel Covered Arc Welding Electrodes* (unless indicated)
§ per ANSI/AWS A5.29, *Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding* (use with CO_2 or Ar-CO_2 mixture)
‖ per ANSI/AWS A5.23, *Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*
\# no match, consider higher alloy than base metal
** no match, use between 2¼Cr-1Mo and 5Cr-½Mo
†† per ANSI/AWS A5.9, *Specification for Bare Stainless Steel Welding Electrodes and Rods*
‡‡ per ANSI/AWS A5.4, *Specification for Covered Corrosion-Resistant Chromium and Chromium-Nickel Steel Welding Electrodes*
§§ no match, use between 5Cr-1Mo and 9Cr-½Mo

Figure 39-8. *Filler metals for welding chrome-moly steels may be slightly more alloyed in order to minimize the number of filler metal types required.*

Nickel Steels. To weld nickel steels where the tensile strength of the weld must be equal to that of the base metal, low-alloy nickel filler metals in the E80XX series are generally used. Examples are E8016-C1, E8018-C2, and E8018-C3. On thick metal, preheat to a dull red is generally advisable.

Austenitic Manganese Steels. Austenitic manganese steels require care when welding as they experience loss of ductility when reheated. A low welding current and rapid welding speed must be used, without extensive preheat. Care must be taken to prevent an excessive amount of base metal from mixing into the weld. A slight preheat is advisable to reduce underbead cracking. Postheating is recommended for stress relief. Use the following guidelines to ensure quality welds when welding austenitic manganese steel:

- V the joint and clean the surfaces carefully and thoroughly.
- Use the lowest possible current to prevent the formation of a brittle zone next to the weld.
- Use a stainless steel 18-8 type electrode.

Use the lowest possible current when welding austenitic manganese steel.

Other types of filler metals used for welding austenitic manganese steel are molybdenum-copper-manganese and nickel-manganese. However, more skill is needed to produce good welds with these filler metals. Do not weld in a localized area for an extended time unless the temperature of the metal is below 750°F (399°C). Use temperature-indicating crayons to determine temperature by marking the base metal ⅜″ to ½″ from the weld. The welder should be able to place a hand within 6″ to 8″ of the weld at any time. If necessary, place wet rags on

areas adjacent to the weld to control heat. The high thermal expansion of austenitic manganese steel may cause residual stresses to develop as the weld cools, and cracks may develop during contraction. To reduce cracking, peen each weld pass when it is completed.

POINTS TO REMEMBER

1. Carbon steels include low-carbon steels, medium-carbon steels, and high-carbon steels. The weldability of carbon steels decreases as the carbon content increases.
2. The principal benefits of alloy steels over carbon steels are higher strength and greater capacity for strengthening in thick sections (hardenability).
3. The deoxidation practice determines the amount of deoxidation performed and the basic steel type produced.
4. Steels that are susceptible to cracking must be preheated to reduce the rate of cooling and decrease the possibility of martensite formation.
5. Hydrogen cracking is often located below the surface and may not be detected by common nondestructive examination techniques.
6. Low-hydrogen filler metals should be used when welding medium-carbon steels.
7. Low-hydrogen filler metals with iron powder coatings usually minimize cracking in welding high-carbon steel.
8. Free-machining steels are not usually welded unless special precautions are taken.
9. Temperature must be maintained between the minimum and maximum interpass temperatures for each succeding welding pass.
10. The recommended preheat temperature for low-alloy steels is about 50°F (28°C) above the temperature at which martensite begins to form on cooling.
11. Before welding any alloy steel, check with the manufacturer for the proper filler metal.
12. Use the lowest possible current when welding austenitic manganese steel.

QUESTIONS FOR STUDY AND DISCUSSION

1. When is steel classified as medium-carbon steel?
2. What is the difference between killed and semikilled steel?
3. Why is some form of preheat recommended when arc welding alloy steels?
4. What are some of the basic characteristics of austenitic manganese steel?
5. What is the function of postheating? At what temperature should postheating be done?
6. What type of filler metal is required for welding medium-carbon steel?
7. Why are high-carbon steels more difficult to weld?
8. What is the purpose of a clip test and how is it conducted?
9. Why must the lowest possible current be used when welding austenitic manganese steel?

Weldability of Tool Steels & Cast Irons

40

Tool steels and cast irons are metals that require special consideration when welding. Tool steels are the most highly alloyed steels and in general are the hardest and strongest steels available. In most cases, the welding of tool steels encompasses the repair of tools or dies that have been hardened and machined to final shape and have failed by wear, chipping, or cracking.

Cast irons are alloys of iron with significant amounts of carbon and silicon, and occasionally other elements. The primary consideration for joining cast irons is to accommodate their poor weldability, the principal cause of which is their high carbon content.

WELDABILITY OF TOOL STEELS

Tool steels are the most highly alloyed steels and in general are the hardest and strongest steels available. Tool steel groups are named for their response to heat treatment or their major end use. The chemical composition and metallurgical structure of tool steels are designed for specific end uses. Tool steel groups consist of water hardening, cold work, shock resisting, hot work, high-speed, mold, and special purpose. See Figure 40-1. Tool steels are very difficult to weld and are not usually welded unless for repair or rebuilding. See Figure 40-2.

Tool steels should be welded in the annealed condition (as they are received from the manufacturer) as this minimizes the tendency to crack on welding.

Water hardening tool steels, Group W, are high-carbon steels that contain between .6% and 1.4% carbon, plus small amounts of chromium and vanadium to increase hardenability and maintain fine grain size to improve toughness. Water hardening tool steels are the least costly and have many applications.

Cold work tool steels (Groups O, A, and D) generally contain between 1% and 2% carbon, and can range from .5% to 2.35% for some alloys. Cold work tool steels have alloy compositions designed to provide moderate-to-high hardenability and good dimensional stability during heat treatment. They have high wear resistance, and poor-to-fair toughness. Cold work tool steels begin to soften at temperatures above 400°F (204°C) and are generally limited to working temperatures below 900°F (482°C). The majority of tool applications can be served by one or more cold work tool steels.

Shock resisting tool steels, Group S, have a relatively low carbon content—between .4% carbon and .65% carbon—and contain manganese, silicon, tungsten, and molybdenum. Shock resisting tool steels are used in applications involving impact loading because of their high strength and toughness under repeated shock and low-to-medium wear resistance.

Tool steels are the most highly alloyed steels and in general are the hardest and strongest steels available.

Tool Steel Alloy Families
Figure 40-1

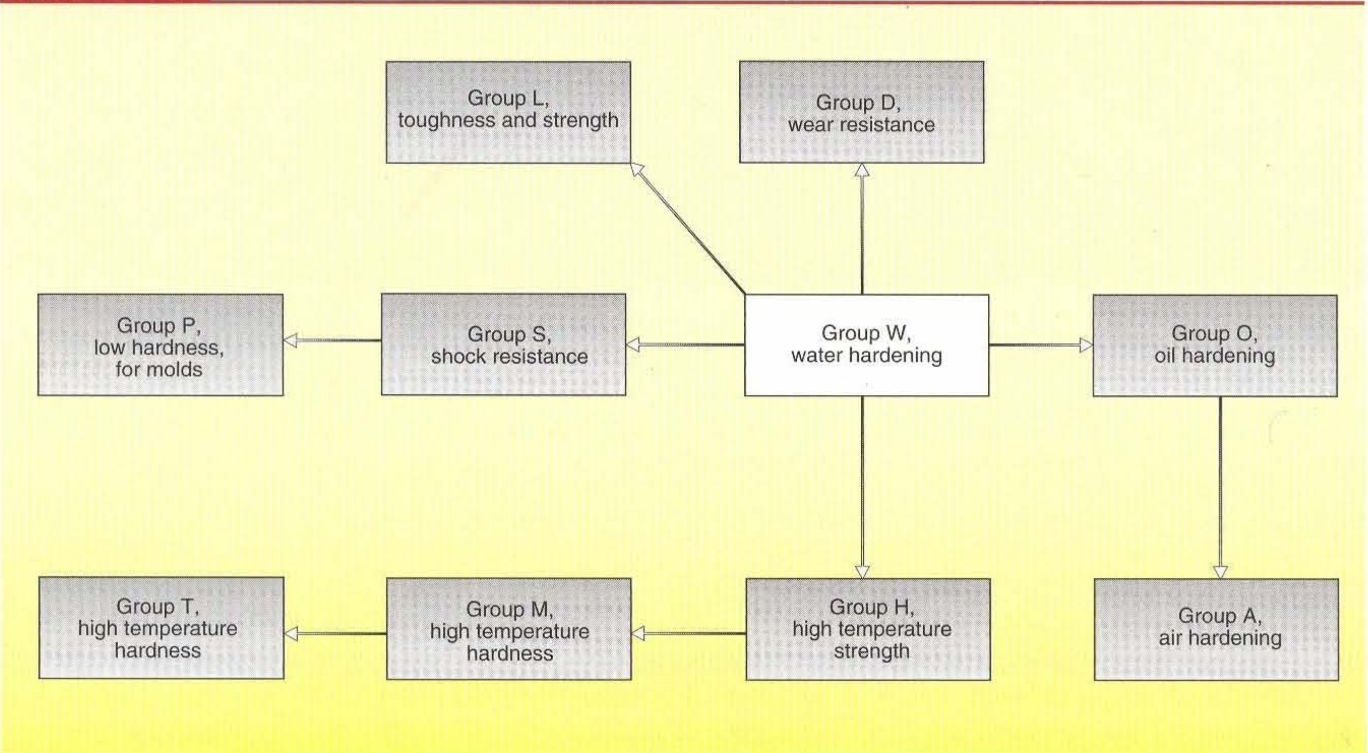


Figure 40-1. *Tool steel groups consist of water hardening, cold work, shock resisting, hot work, high-speed, mold, and special purpose.*

TOOL STEELS		
Tool Steel Group	**Properties and Characteristics**	**Common Use**
Group W	Tough core and hard and wear resistant surface	Cutlery, forging dies, and hammers
Group O	Wear resistant to moderate temperatures	Dies and punches
Group A	Minimum distortion and cracking on quenching	Dies, punches, and forming rolls
Group D	High hardness and excellent wear resistance	Long run dies and brick molds
Group S	Excellent toughness and high strength	Chisels, rivet sets, and structural applications
Group H	Good resistance to softening at elevated temperatures and good toughness	High stressed components and high-temperature extrusion dies
Group T	High hardenability and high hardness	Cutting tools and high-temperature structural components
Group M	High hardenability and high hardness	Cutting tools
Group L	High toughness and good strength	Arbors, cams, and chucks
Group P	Low hardness and low resistance to work hardening	Dies and molds
Group F	Tough core, hard surface, and galling resistance	Burnishing tools and tube-drawing

Figure 40-2. *Diversification of properties and characteristics influence the number and type of uses of tool steels.*

Hot work tool steels, Group H, have a medium carbon content—.35% carbon to .45% carbon—with chromium, tungsten, molybdenum, and vanadium added for total alloying between 6% and 25%. The alloying elements contribute to good hardenability, toughness, and resistance to softening (red hardness) on continuous exposure up to 1000°F (538°C). *Red hardness* is the capacity to resist softening in the red heat temperature range. Hot work tool steels are used for hot die work.

High-speed tool steels, Groups T and M, have high carbon content and relatively large amounts of expensive alloying elements, particularly tungsten (Group T) and molybdenum (Group M). They are resistant to softening up to 1000°F (540°C) but have relatively low toughness. High-speed tool steels are used for high-speed cutting operations because the alloy carbides in their metallurgical structure allow these steels to maintain their cutting edge at high temperatures.

Mold steels and special purpose tool steels, Groups L and P, and Group F, are minor tool steel groups whose properties are tailored to specific applications. Mold steels have a low to medium carbon content and contain chromium and nickel as the principal alloying elements for a total alloy content of 1.5% to 5%. Mold steels exhibit low hardness and low resistance to work hardening in the annealed (softened) condition, which facilitates the formation of mold impressions for cold hobbing operations. Special purpose tool steels contain small amounts of chromium, vanadium, and nickel and are used in applications requiring good strength, toughness, scratch resistance, and galling resistance.

General Welding Considerations for Tool Steels

In most cases, the welding of tool steels encompasses the repair of tools or dies that have been hardened and machined to final shape and have failed by wear, chipping, or cracking. Tools or dies may also be welded to alter the tool or die to accommodate design changes. Due to their high carbon and alloy content, they are extremely prone to hydrogen cracking in the HAZ if rapidly cooled. If high heat input and slow cooling are used to counteract cracking, the weld may be too soft. Welding procedures must be carefully controlled.

Preheat and Postheating Requirements. Tool steels are always preheated for welding. The required preheat temperature depends on the specific alloy, heat-treated condition, and section thickness. When preheating a hardened tool steel, the preheat temperature should not exceed the tempering temperature of the tool steel, or it will soften. The preheat temperature should be maintained between weld passes. After welding, the workpiece should be cooled to about 150°F (65°C) and immediately postheated at the recommended temperature. See Figure 40-3.

Welding Processes. The welding process for tool steels must be carefully selected to produce a quality weld. Welding processes that can be used for tool steels include SMAW, FCAW, and GMAW. SMAW is the most versatile for repair welding small areas. Large areas may be more economically welded with FCAW or GMAW. OFW should not be used for tool steels because it is too slow and introduces excessive heat into the base metal, leading to distortion, softening of hardened metal, embrittlement of annealed metal, or cracking.

OFW should not be used for tool steels because it is too slow and introduces excessive heat into the base metal, leading to distortion, softening of hardened metal, embrittlement of annealed metal, or cracking.

Filler Metals. Filler metals used for tool steels must be carefully selected to ensure a quality weld. Filler metals for welding tool steels fall into three categories: matching, low-alloy steel, and soft. Filler metals that produce deposits matching the basic tool steel type should be used because they produce a surface that matches the wear resistance

of the tool steel. However, filler metals are not available to match all tool steel compositions. Although an exact match may not always be available, using manufacturer trade name products and their recommended procedures usually produces a quality weld.

When matching filler metal is not available, filler metals that produce deposit compositions similar to low-alloy steel may be used as they exhibit moderate hardness. Toughness may be improved by peening. Soft filler metals such as stainless steels, nickel, nickel-copper alloys, and copper-nickel alloys may be used to build up worn parts, followed by a hard wear-resistant deposit that matches the base tool steel composition. Using a soft buildup material minimizes cracking.

Figure 40-3. *The required preheat temperature for tool steels depends on the specific alloy, heat-treated condition, and metal thickness.*

PREHEAT AND POSTHEATING TEMPERATURES FOR TOOL STEELS

Type	Group	Annealed Base Metal		Hardened Base Metal		
		Preheat and Postheating*	Deposit HRC†	Preheat and Postheating*	Tempering Temperature*	Deposit HRC‡
W1, W2	Water-hardening	250–450 (121–232)	50–64	250–450 (121–232)	350–650 (177–343)	56–62
S1	Shock-resisting	300–500 (149–260)	40–58	300–500 (149–260)	400–1200 (204–649)	52–56
S5	Shock-resisting	300–500 (149–260)	50–60	300–500 (149–260)	350–800 (177–426)	52–56
S7	Shock-resisting	300–500 (149–260)	47–58	300–500 (149–260)	400–1100§ (204–621)	52–56
O1	Oil-hardening	300–400 (149–204)	57–62	300–400 (149–204)	350–500 (177–260)	56–61
O6	Oil-hardening	300–400 (149–204)	58–63	300–400 (149–204)	350–600 (177–316)	56–61
A2	Air-hardening	300–400 (149–204)	57–62	300–400 (149–204)	350–1000§ (177–538)	56–61
A4	Air-hardening	300–400 (149–204)	54–62	300–400 (149–204)	350–800§ (177–426)	60–62
D2	Air-hardening	700–900 (371–482)	54–61	700–900 (371–482)	400–1000§ (204–538)	58–60
H12, H13, H19	Hot work	700–1000 (371–538)	38–56	700–1000 (371–538)	1000–1200§ (538–649)	46–54
M1	High-speed	950–1050 (510–566)	60–65	950–1050 (510–566)	1000–1100§ (538–593)	60–63
M2	High-speed	950–1050 (510–566)	60–65	950–1050 (510–566)	1000–1100§ (538–593)	60–63
M10	High-speed	950–1050 (510–566)	60–65	950–1050 (510–566)	1000–1100§ (538–593)	60–63
T1, T2, T4	High-speed	950–1050 (510–566)	60–66	950–1050 (510–566)	1000–1100§ (538–593)	61–64
P20	Mold steel	800–1000 (426–538)	28–42	800–1000 (426–538)	900–1100 (480–595)	28–37

* °F (°C)
† hardness varies with heat input and cooling rate
‡ after postheating and tempering, varies with heat input and cooling rate
§ double temper

Repair Welding. Repair welding requires adequate preparation. Preparation for repairs requires first grinding the damaged area to a uniform depth to allow for buildup of a deposit with the required hardness and wear resistance. A groove depth of ⅛″ is common. Small weld passes are used to fill the groove. The bead size of the final pass should be adjusted so that the repair is as close as possible to final size to minimize the final grinding operation. Welding is done in flat position with minimum heat input. Intermittent welding is used on symmetrical repairs to ensure uniform heat distribution. The weld should be cleaned frequently by chipping and brushing. Warpage and distortion are counteracted by preheat and peening. When repairing the cutting edge of a tool or die, the edge to be welded should be grooved approximately 45° for sufficient depth. See Figure 40-4.

WELDABILITY OF CAST IRONS

Cast irons are alloys of iron that contain significant amounts of carbon and silicon, and occasionally other elements. Cast irons can be easily poured into complex shapes; however, they are difficult to weld. When casting defects occur, or components break in service, repairs can be made (except on white iron) by welding or braze welding.

Repairing Tool Steels
Figure 40-4

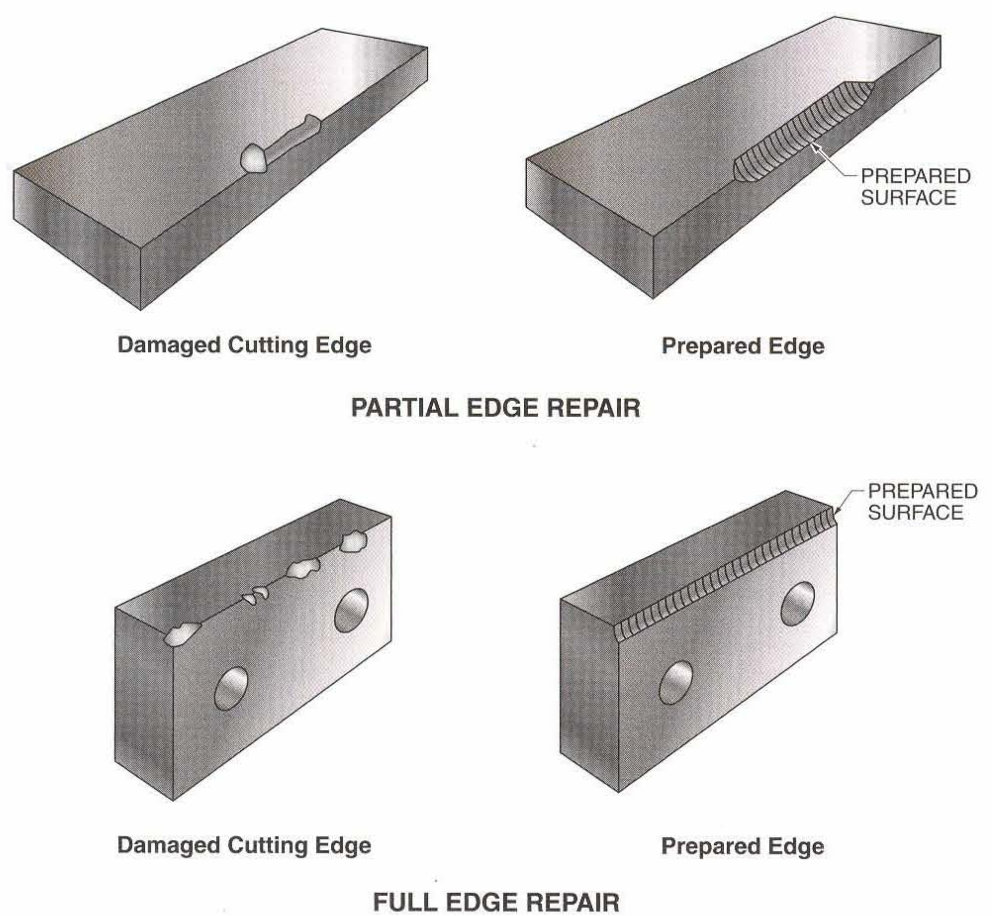


Figure 40-4. *The buildup area is grooved when repair welding tool steels to allow sufficient metal to be deposited.*

Cast irons are used for wear and corrosion resistance and for general applications where good castability is needed.

Cast irons are used for wear and corrosion resistance and for general applications where good castability is needed. Cast irons are grouped according to their metallurgical structure into gray irons, white irons, malleable irons, ductile irons, compacted graphite irons, and alloy irons. See Figure 40-5.

A gray iron microstructure consists of pearlite (iron carbide and ferrite), ferrite, or martensite. All three types of gray iron microstructures contain an even distribution of graphite flakes. The graphite flakes make gray irons extremely brittle but also provide for the highest damping capacity of any engineering material, high temperature scaling resistance, and thermal shock resistance.

Gray iron is the most widely used cast iron. Gray iron can be identified by its dark gray, porous structure on the fracture face. When using the spark test to identify gray iron, short, brick-red streamers are given off that follow a straight line and have numerous fine, repeating yellow sparklers. Gray iron is relatively easy to arc weld.

Gray irons are used for bases and supports for moving components to dampen vibrations; in pressure applications such as cylinder blocks; for wear-resistant and scuff-resistant materials in cylinder sleeves; and for general municipal applications such as manhole covers and hydrants.

White irons are formed when carbon does not precipitate as graphite during solidification but combines with iron or alloying elements such as molybdenum, chromium, or vanadium to form iron carbide or alloy carbide. This combining occurs because of fast cooling of the molten metal in the mold. Thus, white iron can be formed if the mold contains coolers that accelerate the cooling rate. The carbides make white iron extremely hard, wear-resistant, and brittle.

Cast Iron Alloy Families
Figure 40-5

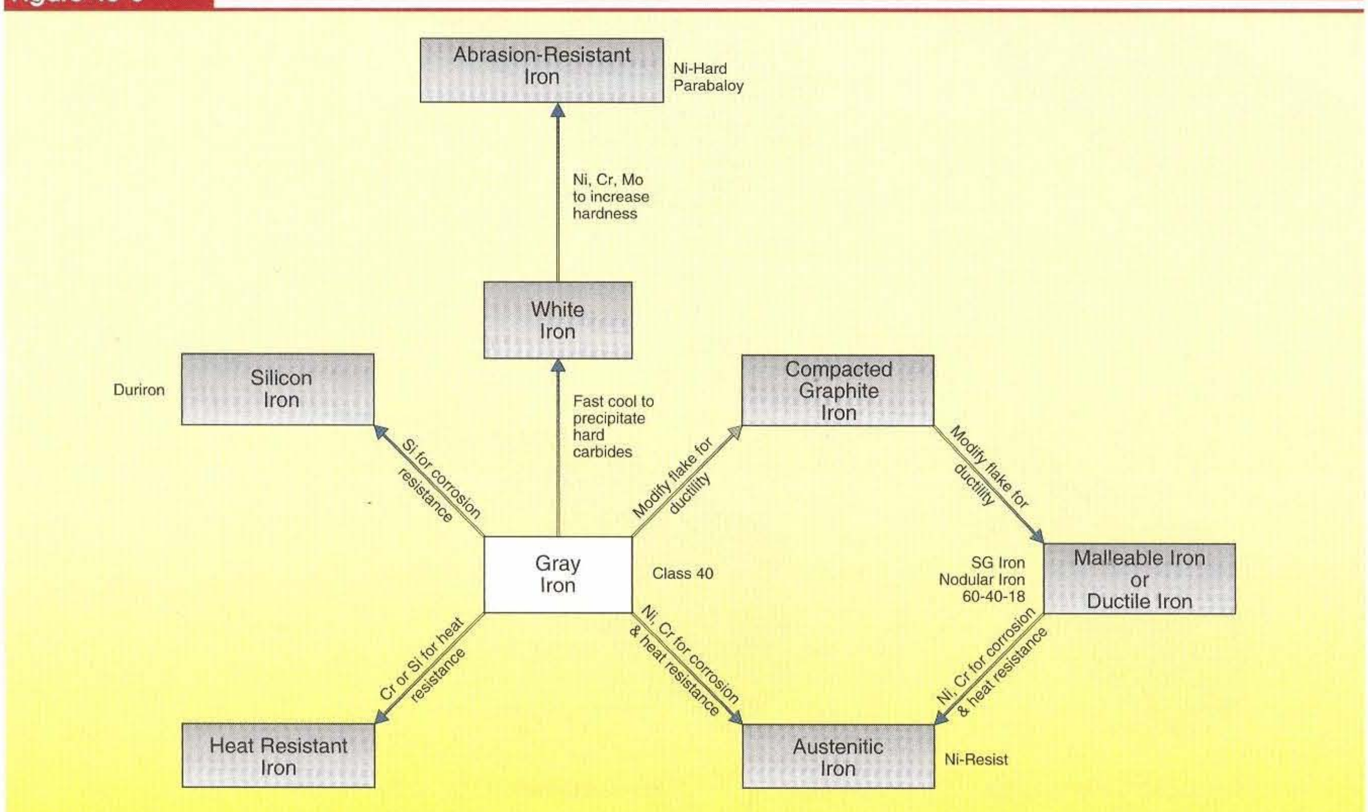


Figure 40-5. *Cast irons are grouped according to their metallurgical structure into gray irons, white irons, malleable irons, ductile irons, compacted graphite irons, and alloy irons.*

White irons have a fine, silvery white, silky, crystalline fracture face. When spark tested, white iron shows short, red streamers. There are fewer sparklers than in gray cast iron and these are small and repeating. Welding is not recommended for white irons. White iron is used for wear plates.

Malleable irons are a ductile form of iron produced by heat treating white iron. Malleable iron can be welded. However, the metal must not be heated above its critical temperature (approximately 1382°F [750°C]). If it is heated above the critical temperature, the metal reverts to the original characteristics of white iron.

Heat treatment transforms graphite flakes into nodules, leading to increased ductility. Improved ductility creates many uses for malleable iron. These include axle and differential housings, camshafts, and crankshafts in automobiles; and gears, chain links, sprockets, and elevator brackets in conveying equipment.

Malleable irons exhibit a white crystalline fracture face with a dark center. A spark test shows a moderate number of short, straw-yellow streamers with numerous sparklers that are small and repeating.

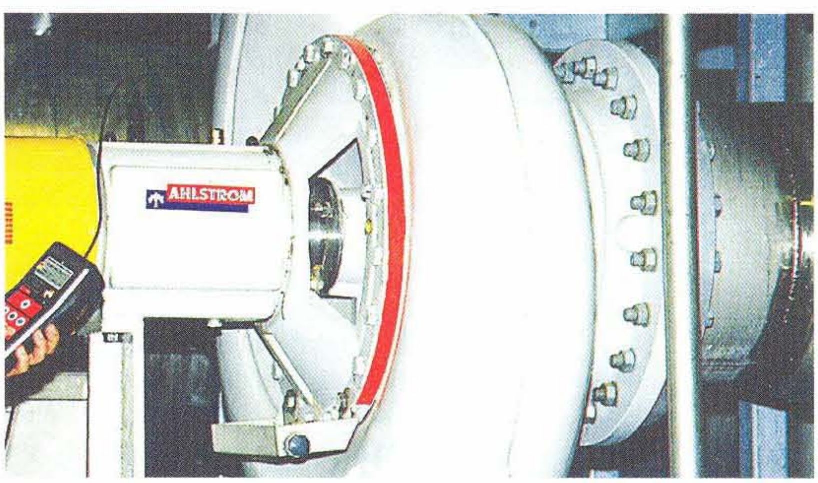
Ductile irons contain amounts of carbon and silicon similar to gray irons, but differ in the shape of the graphite constituent. In ductile iron, the graphite is spheroidal (nodular) in shape, rather than in the form of flakes. Ductile iron is also called spheroidal graphite (SG) iron or nodular iron.

Spheroidization of the graphite is achieved by adding small amounts of magnesium or cerium to molten iron before it cools and solidifies. The cost of the elements added to the iron makes ductile iron more expensive, but prolonged heat treatment is not required, so that its cost is comparable to malleable iron. Grade for grade, ductile iron has strength equivalent to gray iron, but ductile iron has significantly greater elongation.

Ductile irons can be arc welded, provided adequate preheat and postheating are used; otherwise, some of the original properties are lost. Ductile iron is used for many structural applications, particularly those requiring strength and toughness, and combines good machinability at low cost. Ductile iron is used for items such as crankshafts, front wheel spindle supports, steering knuckles, and pumps. Piping such as culvert, sewer, and pressure pipe is another application for ductile irons.

Compacted graphite iron exhibits a graphite shape between that of the flakes in gray iron and the spheroids in ductile iron. Compacted graphite irons are produced by adding specific elements to the molten metal in a way similar to ductile irons. The resulting graphite is in the form of interconnected flakes with blunted edges and a relatively short span. The intermediate shape of the graphite results in a combination of properties between gray and ductile iron. Compacted graphite irons are used for specific applications, such as disc brake rotors and diesel engine heads.

Alloy irons are cast irons that contain one or more added alloying elements, such as chromium, nickel, copper, molybdenum, vanadium, and silicon, to a total of up to 30% of the final composition. The three subgroups of alloy irons are abrasion-resistant irons, corrosion-resistant irons, and heat-resistant irons.



SPM Instrument, Inc.

Ductile irons are commonly used for pumps in industrial applications.

Abrasion-resistant irons are alloys of white iron and include the Ni-Hard® (nickel-containing) irons and the chromium irons. Abrasion-resistant irons are used for abrasive materials handling, as in slurry pumps, grinding equipment, and mud pump liners in well drilling.

Corrosion-resistant irons may be nickel-containing types such as the Ni-Resist® series or silicon-containing types such as the Duriron® series. Nickel-containing types are used in many corrosion-resistant applications, such as pump impellers and casings for seawater, acids, and sour gas. Silicon-containing types are brittle but possess exceptional corrosion resistance and are used for pumps, agitators, mixing nozzles, and valves.

Heat-resistant irons are gray or ductile irons containing alloying elements to improve high-temperature strength and oxidation resistance. They are used for turbine diaphragms, valves, and nozzle rings; manifolds and valve guides for heavy-duty engines; burner nozzles; glass molds; and valve seats for engines.

Most alloy irons can be arc welded, but precautions must be taken during preheat and postheating to prevent compromising desired metallurgical properties.

All casting skin and foreign matter must be removed from the joint surface and adjacent areas of cast irons before welding.

General Welding Considerations for Cast Irons

Cast irons are difficult to weld and heat input and joint preparation must be carefully controlled. Welding or braze welding can be used to repair broken castings, correct machining errors, fill defects, or weld cast iron to steel.

The primary consideration for joining cast irons is to accommodate their poor weldability, the principal cause of which is their high carbon content. A high carbon content can lead to the formation of very hard martensite in the HAZ, which, coupled with low ductility and the presence of residual stress, increases the susceptibility of cast iron to cracking.

The feasibility of repairing cast irons that have been in service depends on the service conditions. For example, it is generally not recommended to repair weld gray iron castings that are subject to repeated heating and cooling in normal service, especially if the temperature range exceeds 400°F (204°C). Unless cast iron is used as filler metal, the different coefficient of expansion between the weld metal and filler metal causes stresses that lead to cracking.

Mechanical joining techniques or braze welding are often effective alternatives to welding on cast irons. Mechanical joining methods may be used for joining cast iron if pressure retention is not a concern. The principal mechanical joining method for cast irons is cold mechanical repair. Parameters that must be considered before welding cast irons include joint preparation, heat requirements, welding processes, filler metals, repairing cracked castings, and studding broken castings.

Joint Preparation. Cast iron must be completely cleaned of contaminants around the weld area before welding. Joint preparation must ensure that the filler metal can thoroughly bond to the base metal. All casting skin and foreign matter must be removed from the joint surface and adjacent areas. Where possible, the casting is heated uniformly using an oxyacetylene torch at 700°F (371°C) for 30 min, or less than 30 min at 1000°F (538°C). Graphite on the surface of gray iron can be oxidized by searing the surface with an oxidizing flame or by heating the casting with a strongly decarburizing flame, followed by wire brushing to remove debris.

To prepare cast iron for welding, grind a narrow strip along each edge of the joint to remove the surface film or casting skin. V the edges of the weld area. On metal less than 3/16″ thick, no V is necessary. On metal 3/16″ to 3/8″ thick, a single-V joint is required with a groove angle of approximately 60°. Metal 3/8″ thick or more requires a

double-V joint with a 1/16″ to 3/32″ root face. The groove angle should be 60°. See Figure 40-6.

Cast Iron Joint Preparation
Figure 40-6

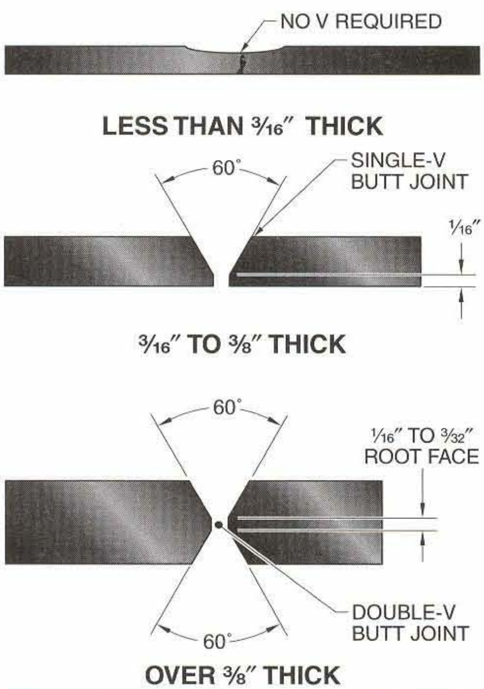


Figure 40-6. *Careful joint preparation is required when welding cast iron.*

Heat Requirements. Preheat and postheating help minimize cracking and relieve residual stress. The preheat temperature depends on the type of cast iron, its mass, the welding process, and the welding filler metal. The preheat temperature should be monitored with a contact pyrometer, temperature-indicating crayon, or thermocouple to ensure accuracy. With large or complex castings, the preheat rate must be slow and uniform to prevent cracking from unequal expansion. The casting should be maintained at a constant temperature until the weld is completed. If possible, preheat the entire welded section with an oxyacetylene torch.

When a high preheat temperature such as 1200°F (649°C) is used, postheating may not be necessary if the casting is allowed to cool slowly from the welding temperature. Slow cooling may be achieved by covering the casting with an insulating blanket, vermiculite, or sand. If slow cooling is not possible, postheating is required.

When it is impossible to preheat the workpiece, the weld temperature can be controlled by depositing short weld beads 2″ to 3″ long. After a bead is deposited, allow it to cool until it can be touched with the hand. Consecutive beads should not be started until the previous bead has cooled sufficiently. As the weld bead cools, peen it by striking it lightly with a hammer. Peening helps to tighten the weld and relieve stress on the cast iron. Peening can be done only on the machinable weld deposit and heat affected zone, not on the entire casting. See Figure 40-7.

⚠ CAUTION

Never postheat cast iron above a dull red color or above a temperature of 1200°F (649°C).

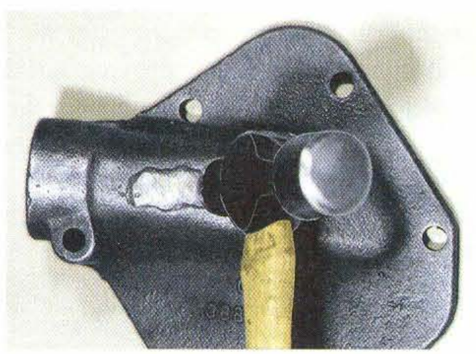


Figure 40-7. *Peening helps to relieve stresses when welding cast iron.*

Postheating is mandatory to stress-relieve fully restrained welds or welds intended for severe service. Postheating is performed immediately after welding by increasing the temperature to 1000°F (538°C) to 1150°F (621°C), followed by holding the casting at temperature for about 1 hr per inch of thickness. The cooling rate must be kept to 50°F (10°C) per hour until the casting reaches 700°F (371°C). Postheating slows the cooling rate, reduces hardness in the weld, and improves the machinability of the HAZ.

Welding Processes. Welding processes that can be used for cast irons include SMAW, GMAW, FCAW, and OFW. Brazing is used for some applications; soldering is not commonly used. SMAW is the most versatile process and can use all types of filler metals. GMAW with short circuiting transfer is suitable for joining ductile iron. Because of the relatively low heat input with GMAW, the hard portion of the HAZ is confined to a thin film next to the weld metal, so that the strength and ductility of the weld joint are about the same as the base metal.

OFW requires extensive heat input during preheat and welding. The high heat input is a limitation of OFW when welding finished or semi-finished castings because it may distort the metal. However, the slower cooling rate lessens the tendency toward brittleness. A high preheat temperature of 1100°F (593°C) to 1200°F (649°C) is required for OFW to compensate for the low welding heat obtained during OFW.

Buttering is used to provide good weld joint ductility and eliminates the need for postheating for the entire completed joint. Buttering places the HAZ of the welded joint in the buttered layer rather than in the cast iron. A layer of weld metal about .03″ thick is deposited (buttered) on the joint faces andthe part is immediately postheated.

Filler metals used for welding cast irons can be composed of nickel alloy, carbon steel, or cast iron.

Filler Metals. Filler metals used for welding cast irons can be nickel alloy, carbon steel, or cast iron. Copper alloy filler metals are used for braze welding cast iron. Nickel alloy filler metals may also be used for buttering. Filler metals that match the base metal may be used, although a filler metal that minimizes cracking should always be used. The composition of the filler metal used to weld cast iron varies depending on the requirements of the weld. See Figure 40-8. Factors that influence filler metal selection for cast iron include the following:

- type of cast iron, mechanical properties desired in the joint
- the need for the filler metal to deform plastically and relieve welding stresses
- machinability of the joint
- color matching between the base metal and the filler metal
- allowable dilution
- cost

Nickel alloy filler metals are specially designed for welding cast irons. They dilute with the base metal and expand on cooling to minimize solidification shrinkage and reduce residual stress. Nickel alloy filler metals are machinable. The use of nickel alloy filler metals reduces preheat to minimal values, except in highly restrained sections. Peening of the hot weld bead helps to reduce residual stresses and maintain dimensions. Two common nickel alloy filler metals are:

- ENi-Cl (nickel) filler metal. DCEP or AC, general-purpose welding, used for thin and medium cast iron sections, castings with low phosphorus content, and where little or no preheat is used.
- ENi-FeCl (nickel-iron) filler metal. DCEP or AC, for welding heavy cast iron sections, high-phosphorus castings, high-nickel alloy castings where high-strength welds are required, and for welding nodular iron.

Carbon steel filler metals are nonmachinable and are used primarily to repair small, cosmetic casting defects with SMAW, where a fair color match is acceptable and machining is not of major concern. Carbon steel filler metals are prone to embrittlement from carbon pickup by dilution with the base metal and should not be used where the joint is loaded in tension or bending. The welding procedure is designed to minimize heat input to keep dilution to an acceptable level.

Carbon steel filler metals consist of a low-carbon steel core and a heavy coating that melts at low temperatures,

allowing a low welding current. Carbon steel filler metals leave a very hard deposit and are used only when the welded section is not to be machined afterward. Nonmachinable carbon steel filler metals produce a tight and nonporous weld, making them ideal for repairing motor blocks, transmission cases, compressor blocks, pulley wheels, pump parts, mower wheels, and other similar structures.

Cast iron filler metals are also nonmachinable and have limited application for repair welding of gray iron and ductile iron castings. Cast iron filler metals are most often used for SMAW or OFW. For SMAW, cast iron filler metals have the composition of gray iron and are used to repair gray iron castings. For OFW, filler metal compositions matching gray iron or ductile iron are used, with other elements added to improve specific properties. A flux is also required with OFW to increase fluidity and remove slag that forms in the weld pool. Extensive heat input is required before, during, and after welding to prevent cracking.

Extensive heat input is required before, during, and after welding cast iron to prevent cracking.

FILLER METALS FOR ARC WELDING OR BRAZE WELDING OF CAST IRON			
Description	**Filler Metal Form**	**Classification**	**Welding (or Braze Welding) Process***
NICKEL ALLOY FILLER METALS			
93 Ni	Bare	ERNi-CI	GMAW
95 Ni	Covered	ENi-CI, ENi-CI-A	SMAW
53 Ni-45 Fe	Covered	ENiFe-CI, ENiFe-CI-A	SMAW
53 Ni-45 Fe-4.5 Mn	Flux Cored	ENiFeT3-CI	FCAW
55 Ni- 40 Cu-4 Fe	Covered	ENiCu-A	SMAW
65 Ni-30 Cu-4 Fe	Covered	ENiCu-B	SMAW
44 Ni-44 Fe-12 Mn	Bare	ERNiFeMn-CI	GMAW
53 Ni-45 Fe-4.5 Mn	Flux Cored w/Flux 5†	ENiFeT3-CI	SAW
44 Ni-44 Fe-12 Mn	Bare w/Flux 6†	ERNiFeMn-CI	SAW
44 Ni-44 Fe-12 Mn	Bare	ERNiFeMn-CI	GTAW
44 Ni-44 Fe-12 Mn	Covered	ENiFeMn-CI	SMAW
CARBON STEEL FILLER METALS			
Carbon Steel	Covered	ESt	SMAW
Carbon Steel	Covered	E7018	SMAW
Carbon Steel	Bare	E70S-2	GMAW
CAST IRON FILLER METALS			
Gray Iron	Welding Rod	RCI	OAW
Alloy Gray Iron	Welding Rod	RCI-A	OAW
Ductile Iron	Welding Rod	RCI-B	OAW
COPPER ALLOY FILLER METALS			
Low-fuming Brass	Welding Rod	RCuZn-B	OAW
Low-fuming Brass	Welding Rod	RCuZn-C	OAW
Nickel-Brass	Welding Rod	RBCuZn-D	OAW
Copper-Tin	Covered	ECuSn-A	SMAW
Copper-Tin	Bare	ERCuSn-A	GMAW
Copper-Aluminum	Covered	ECuAl-A2	SMAW
Copper-Aluminum	Bare	ERCuAl-A2	GMAW

* OAW, oxyacetylene welding; SMAW, shielded metal arc welding; GMAW, gas metal arc welding; SAW, submerged arc welding; GTAW, gas tungsten arc welding

† Incoflux 5 and Incoflux 6 are proprietary fluxes from Special Metals, Inc.

Figure 40-8. *Filler metals for welding or braze welding cast iron are selected based on the requirements of the weld and the welding process.*

The correct current setting for cast iron welding should always be used. The correct current is commonly suggested by the filler metal manufacturer. Generally, the current setting for welding cast iron is lower than for welding carbon steel. The heat applied to cast iron during welding must be kept to a minimum. To ensure that only the minimum heat necessary is used, always use small-diameter filler metals. Welders seldom use filler metals greater than ⅛″ in diameter.

For SMAW, welding current should be as low as possible but within the manufacturer's recommended range for consistent, smooth operation, desired bead contour, and good fusion. When welding in vertical position, current should be reduced by about 25%. When welding in overhead position, current should be reduced by about 15%. For FCAW and GMAW of cast iron, as-deposited nickel alloy filler metal compositions are similar to those used with SMAW.

Copper alloy filler metals are used for braze welding cast iron. The joint is soft and ductile when hot and yields during cooling, so that residual stress is reduced.

To perform braze welding, a brazing filler metal is deposited into the weld joint. There is no melting of the base metal adjacent to the joint. After the surface is heated, a thin layer of filler metal is added to the surface to help ensure a satisfactory bond. A welding tip with high heat output at low gas pressure should be used to provide a soft flame that will not blow the flux away from the joint. After braze welding, the metal should be cooled slowly to prevent white cast iron from forming. The deposited metal is machinable but does not provide a color match. The quality of braze welding with copper alloy filler metals depends upon the following:

- using wide grooves
- thoroughly cleaning joints of moisture, grease, oil, and dirt before welding
- using a preheat temperature between 250°F (150°C) and 400°F (205°C)
- using the lowest possible current for good bonding
- welding at a fast speed to minimize dilution
- preventing puddling
- cooling the part slowly after braze welding

Three common filler metals for brazing cast iron are ECuSn-A and ECuSn-C (copper-tin classification), and ECuAl-A2 (copper-aluminum classification). The main difference between ECuSn-A and ECuSn-C is the amount of tin they contain. The ECuSn-C filler metal has a higher percentage of tin (8%) than ECuSn-A filler metal (5%), thereby producing welds with greater hardness, tensile strength, and yield strength. Both are used with DCEP and normally require that the area to be brazed be preheated to 400°F (205°C).

The ECuAl-A2 filler metal has a relatively low melting point and high deposition rate at lower current, which permits fast welding. A faster welding speed minimizes distortion and the formation of white cast iron in the weld zone. The tensile strength and yield strength of the deposits is nearly double that of copper-tin deposits.

Repairing Cracked Castings. If a crack in a casting is to be welded, V the crack approximately ⅛″ to 3⁄16″ deep with a diamond-point chisel or with a grinder. On sections that are less than 3⁄16″ thick, V only one-half the thickness of the cast iron. Fine, hairline cracks in a casting can be made more visible by rubbing a piece of white chalk over the surface. The chalk leaves a visible line where the crack is located. Cracks have a tendency to extend during welding because of heat expansion. To prevent crack expansion, drill a ⅛″ hole a short distance beyond each end of the crack.

Start the weld about ⅛″ before the end of the crack and weld back to the hole, filling the hole; then move slightly

beyond the hole. Next, move to the other end of the crack and repeat. Continue to alternate the weld on each end, limiting the length of each weld to 1″ to 1½″ on thin cast iron and 2″ to 3″ on thick cast iron. Allow each section of weld to cool before starting the next section and peen each short bead.

For a crack near the edge of the part, grind open the crack to allow for adequate filler metal access. Weld back from the drilled hole to the start of the crack (the edge of the part). If the crack is longer than 1″ or 2″, use skip welding, otherwise use continuous welding. See Figure 40-9.

Studding Broken Castings. When a casting is 1½″ thick or more and is subjected to heavy stresses, steel studs are used to strengthen the joint. Studding is not advisable on castings less than 1½″ thick because it tends to weaken rather than strengthen the joint.

To apply studs, V the crack and drill and tap ¼″ or ⅜″ holes in the casting at right angles to the sides of the V. Space the holes so the center-to-center distance is equal to three to six times the diameter of the stud. Screw the studs into the tapped holes. The threaded end of the studs should be about ⅛″ to ⅜″ in length and should project approximately ¼″ to ⅜″ above the casting. See Figure 40-10. Deposit beads around the base of the studs, welding them thoroughly to the casting. Remove the slag and deposit additional layers of beads to fill the V.

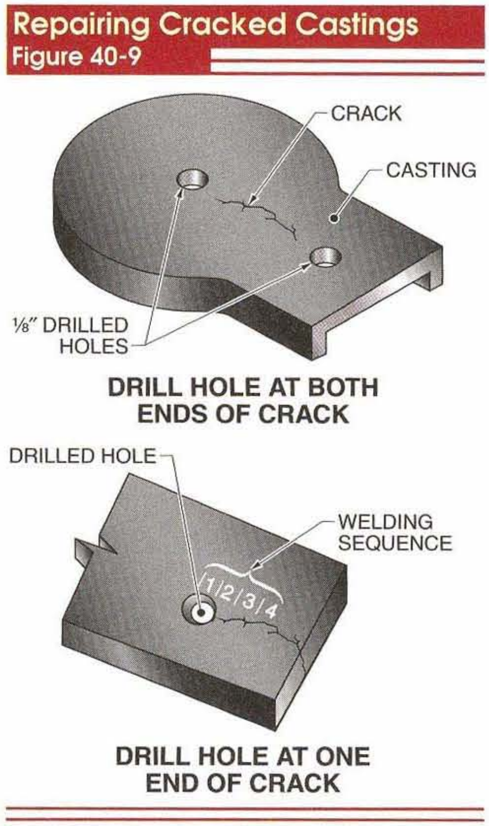


Figure 40-9. *When welding cracks in cast iron, holes are drilled to prevent cracks from extending during welding.*

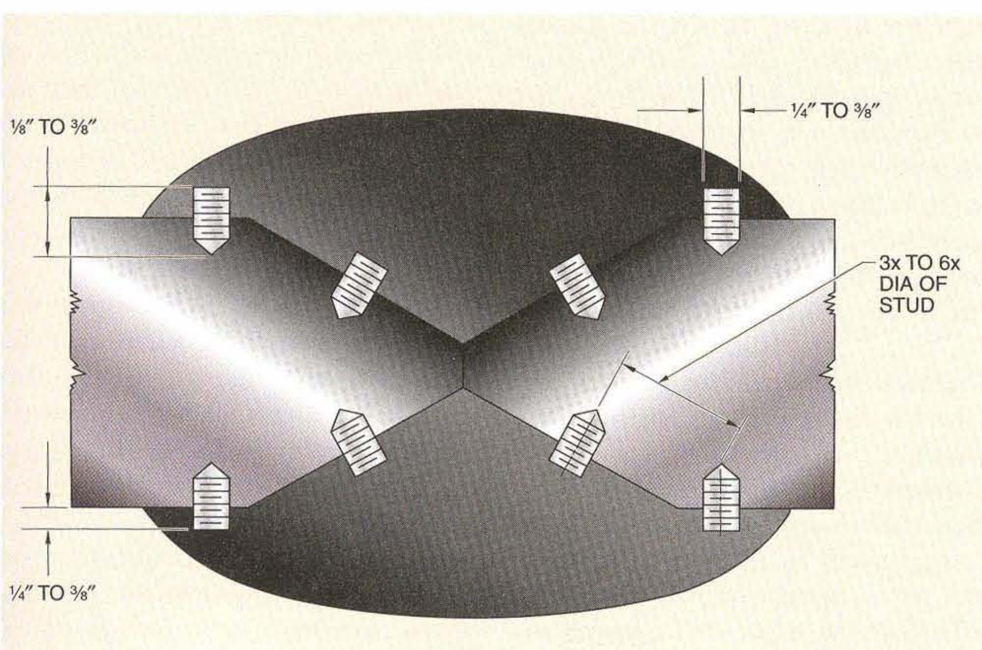


Figure 40-10. *Studding may be used to strengthen the joint when welding castings subjected to heavy stresses.*

POINTS TO REMEMBER

1. Tool steels are the most highly alloyed steels and in general are the hardest and strongest steels available.
2. OFW should not be used for tool steels because it is too slow and introduces excessive heat into the base metal, leading to distortion, softening of hardened metal, embrittlement of annealed metal, or cracking.
3. Cast irons are used for wear and corrosion resistance and for general applications where good castability is needed.
4. All casting skin and foreign matter must be removed from the joint surface and adjacent areas of cast irons before welding.
5. Filler metals used for welding cast irons can be composed of nickel alloy, carbon steel, or cast iron.
6. Extensive heat input is required before, during, and after welding cast iron to prevent cracking.

QUESTIONS FOR STUDY AND DISCUSSION

1. What are some basic characteristics of water hardening tool steels?
2. What alloying elements are added to carbon in hot work tool steels? To what total alloying amount?
3. How should the joints be prepared for welding cast iron?
4. What can be done to make fine cracks in castings more visible?
5. How can cracks in castings be prevented from spreading?
6. What type of filler metal is used for welding the various types of cast iron?

41 Weldability of Stainless Steels

Welding Technology

Stainless steels owe their corrosion resistance to the presence of chromium. Other amounts of alloying elements are added for additional properties.

Stainless steels contain from 12% to 30% chromium plus other alloying elements, such as up to 25% nickel and up to 6.5% molybdenum. Stainless steels consist of five groups named for their metallurgical structure: austenitic, martensitic, ferritic, duplex, and precipitation hardening. The weldability of stainless steels depends on their metallurgical structure.

Welding of stainless steels is also influenced by physical properties and the need for cleaning and joint preparation. Specific welding conditions for stainless steels are dictated by the specific alloy family and will influence factors such as heat input during welding, preheat, and postheating.

WELDABILITY OF STAINLESS STEELS

Stainless steels contain from 12% to 30% chromium (Cr) plus other alloying elements, such as up to 25% nickel (Ni) and up to 6.5% molybdenum (Mo). These create a variety of metallurgical structures, making stainless steels the most versatile family of metals. They are used for their heat resistance, corrosion resistance, and low-temperature toughness. The weldability of stainless steels depends on their metallurgical structure.

Wrought stainless steels consist of five groups named for their metallurgical structure: austenitic, martensitic, ferritic, duplex, and precipitation hardening. Wrought stainless steels are usually identified by a three-digit AISI designation, such as 410 or 316.

Austenitic stainless steels are the largest group and have the widest usage of all stainless steels. They exhibit excellent corrosion resistance, weldability, high-temperature strength, and low-temperature toughness. They cannot be hardened by quenching and are only strengthened and hardened by cold working.

Austenitic stainless steels have varying amounts of Cr and Ni. The basic austenitic stainless steel composition is 18% Cr and 8% Ni although amounts can range from 16% to 26% Cr and 3.5% to 37% Ni. The austenitic structure is achieved by the addition of nickel. Other elements that contribute to the austenitic structure are manganese and nitrogen. Carbon contributes to the austenitic structure, but it is not used in large amounts because it reduces corrosion resistance.

Compared with martensitic stainless steels, austenitic stainless steels are relatively weak. Solution annealing heat treatment is used primarily to improve corrosion resistance. Stress-relief heat treatment, conducted at low temperatures, usually causes distortion and loss of corrosion resistance. Molybdenum is added to austenitic stainless steels to

Stainless steels are used for their heat resistance, corrosion resistance, and low-temperature toughness.

Wrought stainless steels are usually identified by a three-digit AISI designation, such as 410 or 316.

improve corrosion resistance. Standard grades of austenitic stainless steels are the 200 and 300 series. The basic austenitic stainless steel is type 302. See Figure 41-1.

Martensitic stainless steels contain up to 18% chromium and up to 1.5% carbon. They are air hardened and tempered to develop high strength and wear resistance. Martensitic stainless steels contain no alloying elements other than chromium and have the lowest corrosion resistance of the stainless steels. The basic martensitic stainless steel is type 410. See Figure 41-2.

Austenitic Stainless Steel Alloy Families
Figure 41-1

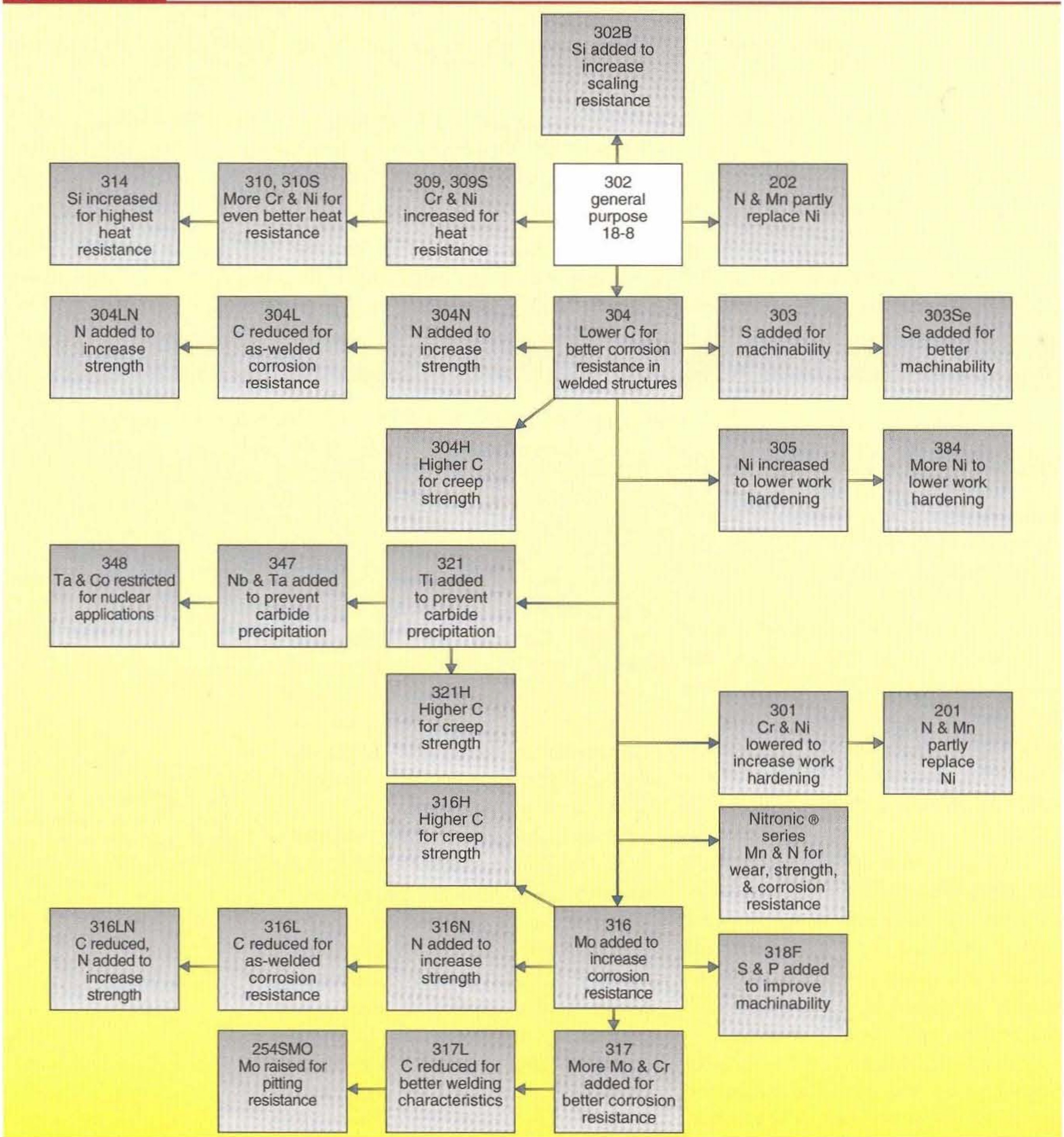


Figure 41-1. *Austenitic stainless steels are nonmagnetic and are strengthened and hardened by cold work.*

Martensitic Stainless Steel Alloy Families
Figure 41-2

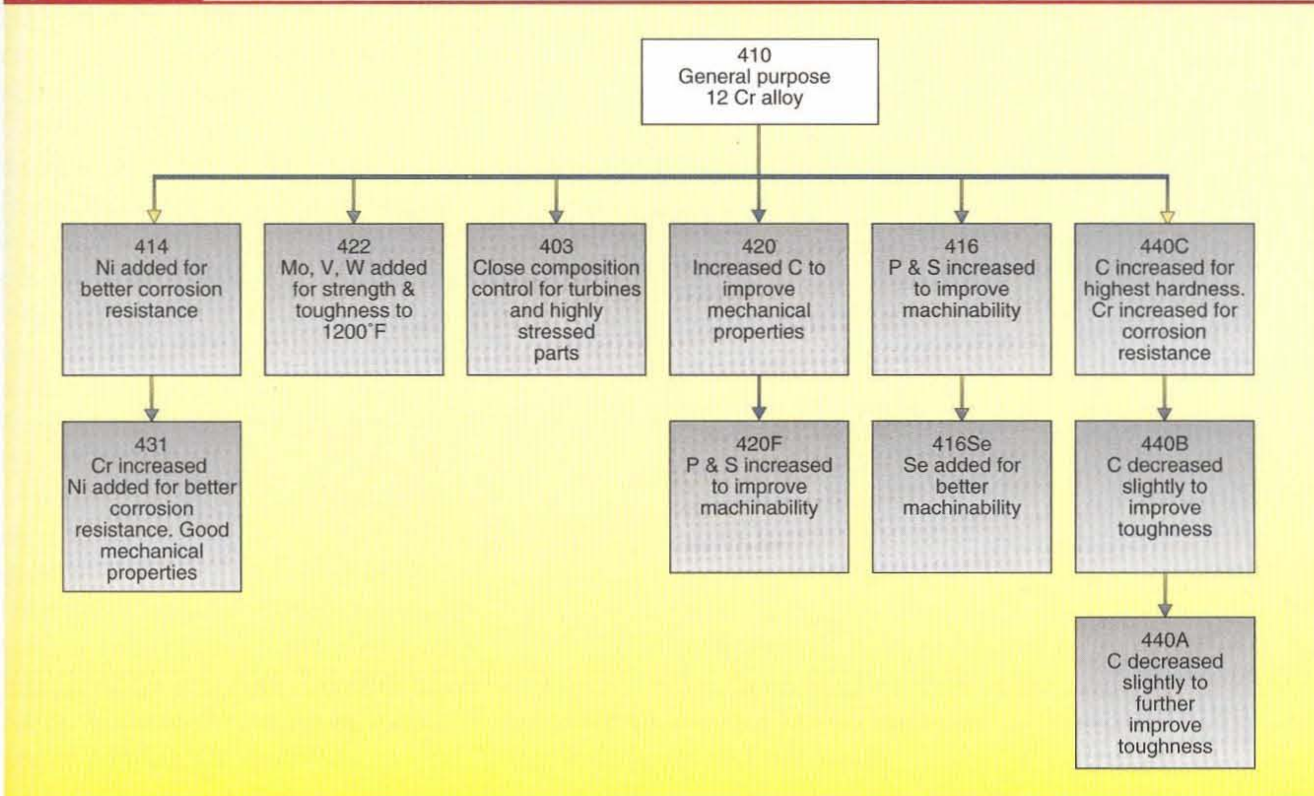


Figure 41-2. *Martensitic stainless steels may be quenched and tempered to improve their strength, and they have the lowest corrosion resistance of all stainless steels.*

Ferritic stainless steels contain more chromium than martensitic stainless steels, which improves their corrosion resistance. Ferritic stainless steels cannot be hardened by quenching and tempering. They are used chiefly for their corrosion and scaling resistance. Ferritic stainless steels are divided into regular ferritics and low-interstitial ferritics. The basic ferritic stainless steel is type 430. See Figure 41-3.

Duplex stainless steels are composite materials whose metallurgical structure consists of approximately equal quantities of austenite and ferrite. The properties of duplex stainless steels are achieved by maintaining a balance of the austenite and ferrite. Properly balanced duplex stainless steels possess certain desirable qualities that austenitic and ferritic stainless steels do not. For example, duplex stainless steels have higher strength and chloride stress-cracking resistance than austenitic stainless steels. They also have better fabricability and toughness than ferritic stainless steels. Heat treatment and fabrication practices for duplex stainless steels must be carefully controlled or significant loss of toughness and/or corrosion resistance may occur. The addition of between .15% N and .25% N helps ensure a balance between austenite and ferrite in duplex stainless steels, especially during welding.

The basic duplex stainless steel is type 329. However, alloying additions, particularly nitrogen, have been carefully controlled to yield a second generation of duplex stainless steels with better control of austenite to ferrite balance during welding operations. These second-generation alloys include types 2205 and 2307. See Figure 41-4.

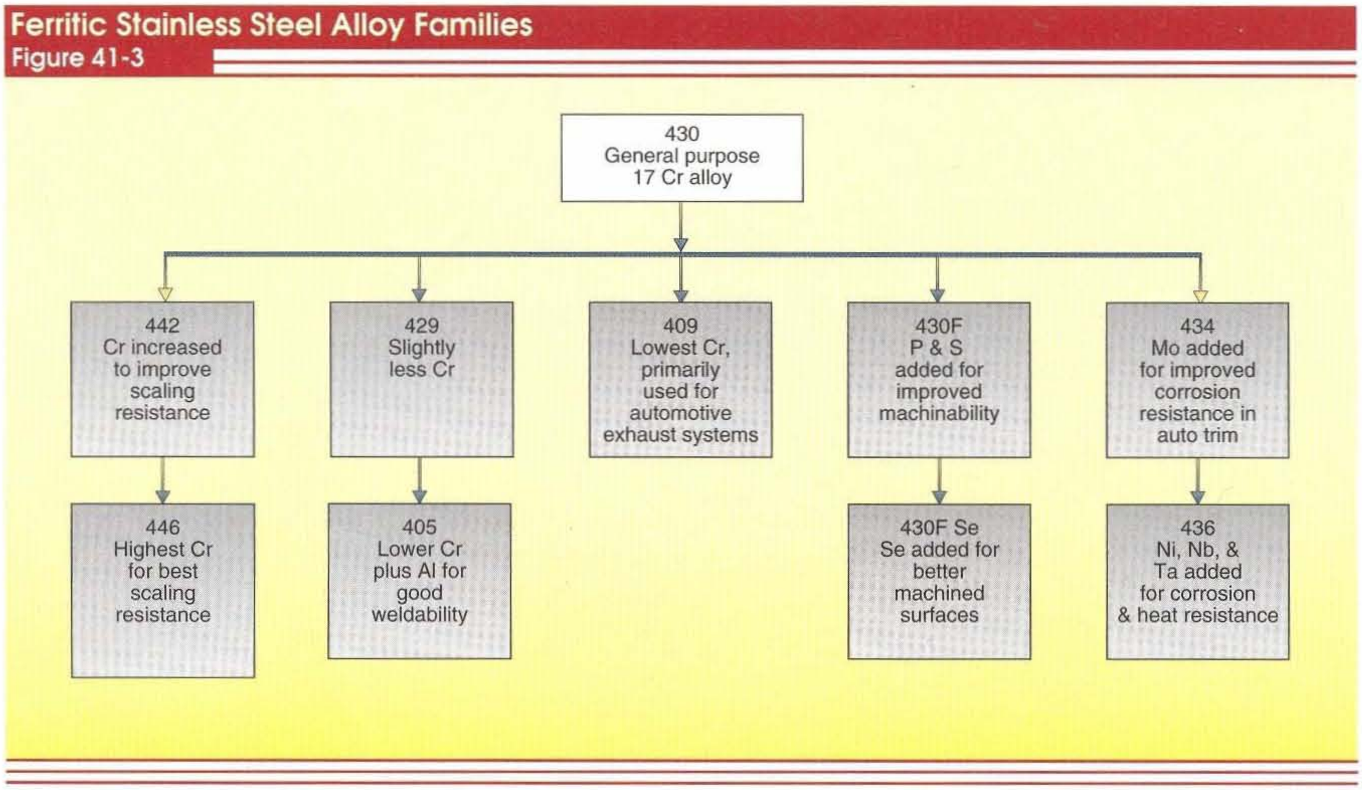
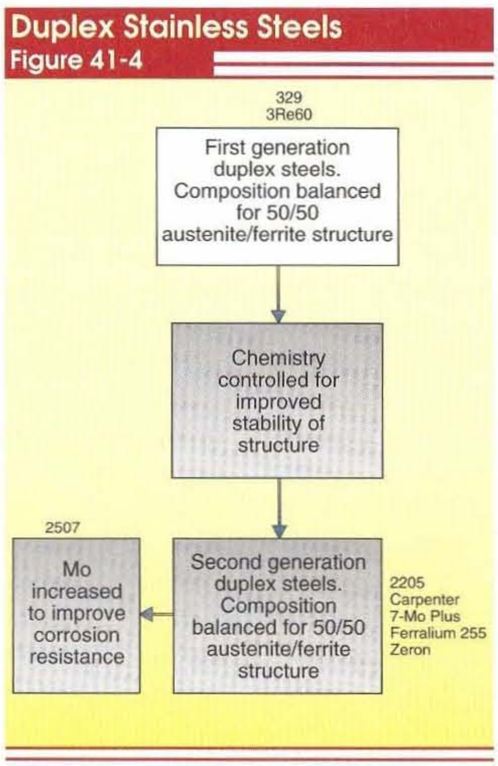


Figure 41-3. *Ferritic stainless steels are relatively low strength alloys that cannot be hardened or strengthened by heat treatment.*

Figure 41-4. *Duplex stainless steels are stronger than ferritic or austenitic stainless steels and consist of a composite structure of austenite and ferrite.*



Precipitation hardening stainless steels are specially alloyed stainless steels that are heat-treated by precipitation hardening to much higher strengths than other stainless steels. They are relatively weak and soft when quenched from the solution annealing temperature. After machining, working, or stamping to the desired shape, they are precipitation hardened to achieve the desired strength and hardness with very little distortion or scaling. The lower the precipitation hardening temperature, the higher the strength, but strength is achieved with a loss of toughness. Higher precipitation hardening temperatures reduce strength but increase toughness. Precipitation hardening stainless steels fall into three subgroups: martensitic, semi-austenitic, and austenitic. See Figure 41-5.

Cast stainless steels exhibit the various metallurgical structures of their wrought stainless steel equivalents. Cast stainless steels are identified by alphanumeric designations such as CF-3M or HK-40.

Precipitation hardening stainless steels exhibit the highest strengths of all stainless steels.

Cast stainless steels may have a martensitic, ferritic, or duplex metallurgical structure. They are divided into corrosion-resistant (C series) and heat-resistant (H series). See Figure 41-6. Corrosion-resistant castings are designated by the uppercase letter C, followed by a letter that indicates the approximate alloy content. The higher the letter (with A considered the lowest and Z considered the highest), the greater the alloy content. Numbers and letters following a dash indicate carbon content and the presence of alloying elements.

Heat-resistant castings include a range of alloy compositions that include stainless steels and nickel alloys. Heat-resistant castings are designated by the letter H followed by a letter indicating the approximate alloy content. The higher the letter, the greater the percentage of alloying elements.

General Welding Considerations for Stainless Steels

Welding of stainless steels is influenced by physical properties, cleaning and joint preparation, and removal of heat tint. Wrought and cast stainless steels can be welded using arc welding or OFW processes. Filler metals of the same or higher alloy content as the base metal must be used to maintain corrosion resistance or mechanical properties.

Effect of Physical Properties. The coefficient of thermal expansion of martensitic and ferritic stainless steels is approximately equal to that of carbon steel. Consequently, the allowances for thermal expansion are practically the same as those for carbon steel. Austenitic stainless steels have about a 50% to 60% greater coefficient of thermal expansion than carbon steel, and are therefore more prone to distortion during welding or heat treatment.

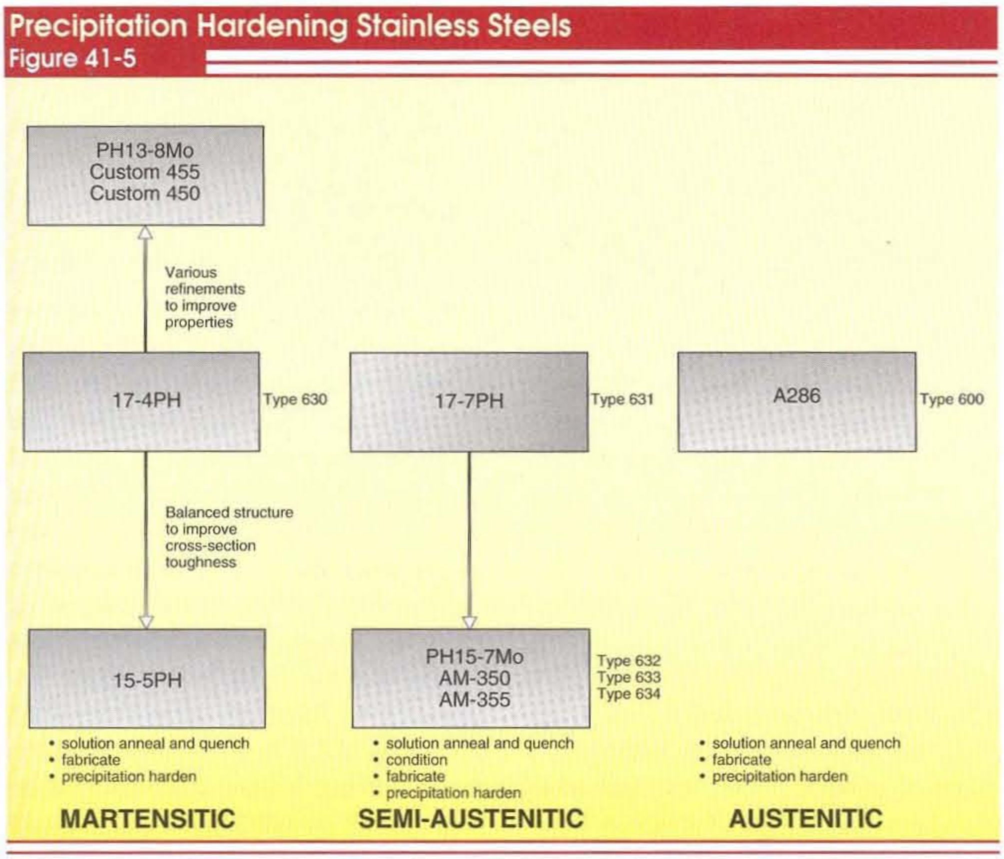


Figure 41-5. *Precipitation hardening stainless steels achieve the highest strengths of all stainless steels through heat treatment.*

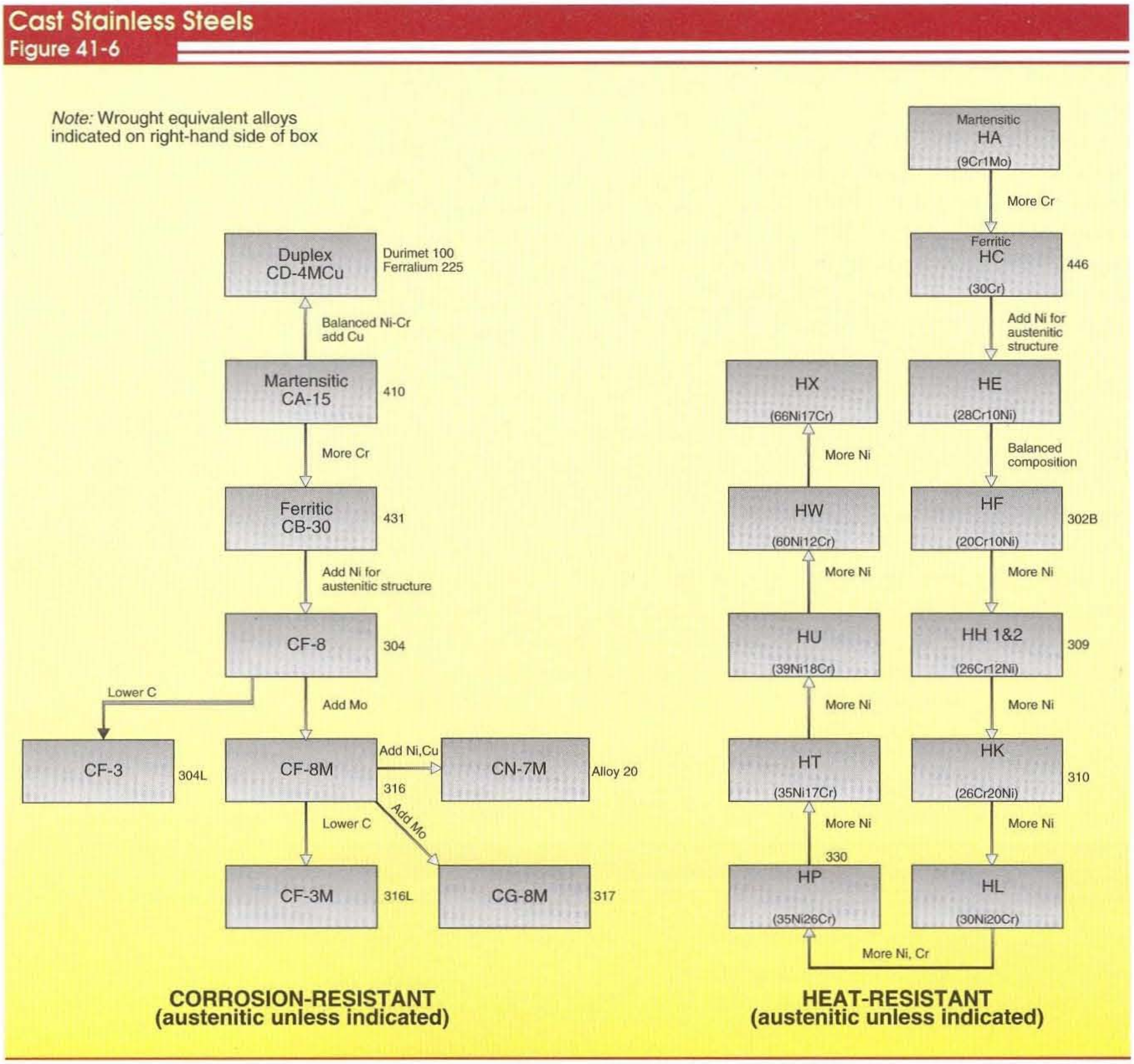


Figure 41-6. *Cast stainless steels exhibit the metallurgical structure of their wrought counterparts and are divided into corrosion-resistant and heat-resistant types.*

When welding stainless steels, using chill plates made of copper helps conduct heat away from the weld area, reducing the unfavorable effects of heat on the alloy.

The thermal conductivity of ferritic and martensitic stainless steels is approximately 50% that of carbon steel, and that of austenitic stainless steels is about 33%. Consequently, heat is conducted away more slowly. As a result, stainless steels take longer to cool. This can be a particular problem when welding thin-gauge steels since there is greater danger of burning through the metal.

Unfavorable effects of heat can be reduced substantially by using chill plates. A *chill plate* is a metal plate used to prevent overheating during welding. The use of chill plates, such as copper plates, helps conduct heat away from the weld area.

Jigs and fixtures should be used whenever possible, especially for austenitic stainless steels. When stainless steels are held in a jig or fixture during cooling, warping and distortion are practically eliminated. If a jig or fixture cannot be used, special welding procedures are necessary to counteract expansion forces. A common practice is to use intermittent welding or back-step welding.

Cleaning and Joint Preparation. Cleaning and joint preparation are critical to ensuring a quality weld. Surface contaminants affect stainless steel welds to a greater degree than carbon and alloy steel welds. The surface of the weld area must also be completely cleaned of all hydrocarbon-containing contaminants such as oils, or chloride-containing cleaning fluids. Contamination from grease and oil must be prevented so that corrosion resistance is not reduced through carbon pickup during welding. In addition to brushing with a clean stainless steel wire brush, other acceptable methods of surface preparation include blasting with clean sand or grit, and machining or grinding with chloride-free cutting fluid.

The area to be cleaned must include the weld groove and adjacent faces for at least ½″ on each side of the groove. Cleaning a wider area is recommended for plate thicker than ⅜″. The surfaces of parts to be resistance welded, spot welded, or seam welded must also be cleaned. The degree of cleaning depends on the welding process. For example, special care is required for cleaning surfaces for gas shielded welding because of the absence of flux, which acts as a cleaning agent. Carbon contamination can adversely affect the metallurgical structure, corrosion resistance, or both. Clean stainless steel wire brushes must be used to prevent carbon and iron pickup. Thorough post-weld wire brushing is used to remove welding slag after welding.

Removal of Heat Tint (Heat Discoloration). Stainless steels obtain their corrosion resistance from a surface film composed largely of chromium and oxygen (chromium oxide). The film forms spontaneously in air or water on alloys that contain more than 10% chromium. The quality of the film must be preserved during fabrication. The physical appearance of the chromium oxide film does not necessarily indicate the overall corrosion resistance of the alloy.

When stainless steel equipment is welded, the chromium oxide film adjacent to the weld thickens from the localized heating effect and changes color due to diffraction of light. The color change is known as heat tint. The presence of heat tint often prompts questions about quality from receivers of stainless steel equipment.

Although heat tint may cause a slight overall chromium depletion in the surface film, it does not usually compromise the ability of the surface film to provide corrosion resistance, unless the stainless steel provides borderline corrosion resistance in the expected service environment. In highly corrosive service environments, it might be necessary to use a more corrosion-resistant stainless steel or nickel alloy. See Figure 41-7.

Heat tint may cause a slight overall chromium depletion in the surface film, but it does not usually compromise the ability of the surface film to provide corrosion resistance.

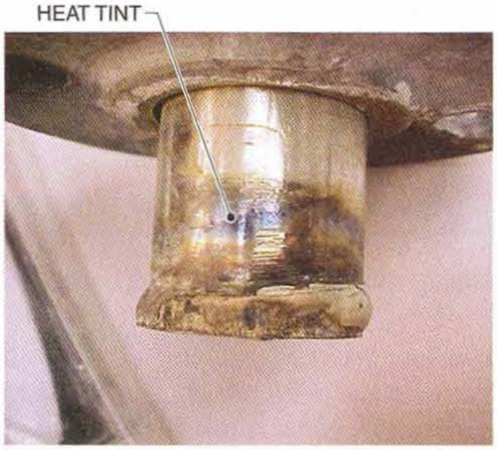
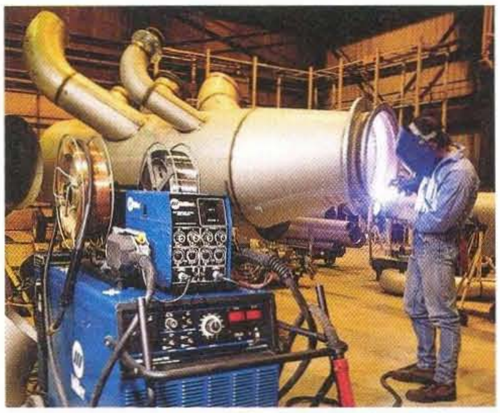


Figure 41-7. *Heat tint is formed on stainless steel during welding but does not usually compromise the corrosion resistance of the stainless steel.*

It may be difficult to remove heat tint, especially from inside corners. Grinding may be used, but is often impractical or expensive. Commercial stainless steel chemical cleaners are available that typically consist of a paste that is painted on the weld seam and allowed to soak for 10 min to 15 min, after which it is removed with a stainless steel wire brush.

Arc Welding Processes. Arc welding processes that can be used for stainless steels include SMAW, GTAW, GMAW, and SAW. OFW is sometimes used for welding 19-gauge and lighter stainless steel sheets. For SAW, a flux suitable for stainless steel welding must be selected.

GTAW or GMAW is used to weld stainless steel because of the ease with which welds can be made. GTAW and GMAW do not significantly reduce the corrosion-resistant properties of stainless steel. See Figure 41-8. GTAW is mostly used for thin sections of stainless steel. A 2% thoriated tungsten electrode is used and is ground to a taper. Argon is normally used as the shielding gas.



Miller Electric Manufacturing Company

Figure 41-8. *GTAW and GMAW welding processes are preferred for welding stainless steel because they minimize heat input and help retain the metal's corrosion-resistant properties.*

GMAW is used for thick stainless steels. Spray transfer is used for flat position welding and requires argon shielding with 2% to 5% oxygen or special mixtures. When welding thin stainless steel with GMAW, short circuiting transfer can be used, in which case 90% He/7.5% Ar/2.5% CO_2 (tri-mix) is the best choice and provides the best weld appearance. When welding extra-low-carbon grades of stainless steel, or if the stainless steel is used in a highly corrosive environment, Ar-CO_2 mixtures should not be used and the CO_2 level must be kept low enough so that the corrosion resistance of the material is not affected.

Joint Design. For thin metal, the flange-type joint is probably the most suitable design. Slightly thicker sheets up to 1/8″ may use a butt joint. For plates thicker than 1/8″, the edges should be beveled to form a V so fusion can be obtained through to the bottom of the weld.

Filler Metals. Filler metal selection for stainless steel welding depends on the base metal. Not every stainless steel has a matching weld filler metal, but there are usually several choices of filler metal for welding any particular stainless steel.

The alloy content of the filler metal should be higher than or the same as that of the base metal to compensate for expected alloy loss. A columbium-bearing filler metal must be used for both the columbium (Type 347) and the titanium (Type 321) stabilized grades of stainless steel. Chromium-nickel filler metals are often used to weld chromium-grade stainless steels because they provide a ductile weld metal. Covered filler metals for SMAW must be stored in heated ovens at 300°F because they are low-hydrogen filler metals and are susceptible to moisture pickup.

Stainless steel filler metals are identified differently from carbon steel filler metals. For example, a standard 18-8 filler metal for AC/DC current is designated as E308-16. The prefix E indicates the filler metal is an arc welding electrode. The next three digits are the AISI symbols for a particular type of metal. Thus, 308 represents a metal containing 18% chromium and 8% nickel. The last two digits following the dash may be either 15 or 16; the 1 indicates all-position welding, and the 5 or 6 specifies the type of covering and applicable welding current. The 5 designates a lime-coated filler metal. The lime type can be used only with DCEP. The 6 indicates a titanium-type covering. The titanium-type can be used with AC and DCEP. See Figure 41-9.

FILLER METALS FOR WELDING STAINLESS STEEL	
Stainless Steel Grade	Filler Metal
AUSTENITIC	
201, 202	308-15, 308-16
301, 302, 304, 305, 308	308-15, 308-16
309	309-15, 309-16
310, 314	310-15, 310-16
316	316-15, 316-16
321, 347, 348	347-15, 347-16
FERRITIC	
405, 409	410-15, 410-16
430, 434, 436, 442	430-15, 430-16
446	446-15, 446-16
MARTENSITIC	
408, 410, 414, 416, 420	410-15, 410-16
431	430-15, 430-16

Figure 41-9. *Electrodes for welding stainless steels are typically identified by their AISI classification.*

Selecting the proper filler metal for stainless steel is, in most cases, a more critical choice than with carbon steel because of the number of types and grades of stainless steel and the varying degrees of severity of heat, corrosion media, etc., to which the weld joint will be subjected. Selecting the right filler metal for satisfactory results requires analyzing all of the conditions that apply to a particular job. To determine the right type and size of filler metal for a given set of conditions, the following factors must be considered:

- chemical composition of the base metal to be welded
- dimensions of the section to be welded
- type of welding current required
- welding position(s) to be used
- fit-up of the section to be welded
- specific properties of the weld deposit
- specific fabrication code requirements

Filler metals must be selected carefully because of the high cost of the material to be welded. The stainless steel weld must have tensile strength, ductility, and corrosion resistance equivalent to the base metal.

Welding Current. Both AC and DC current can be used for arc welding stainless steel. DCEP produces deeper weld penetration and a more consistent fusion when used on stainless steel sheets and light plates.

Since stainless steels have a lower melting point than carbon steel, at least 20% less current is recommended than would ordinarily be used for carbon steel. The low thermal conductivity of stainless steel localizes the heat from the arc along the weld, further reducing current requirements.

Welding Technique. To produce quality welds, square butt joints should be used for stainless steel sheets 18-gauge and less and are fitted up with no gap. Heavier gauge sheets and plates are fitted up with a beveled joint edge preparation and a gap to allow penetration. Metals must be free from scale, grease, and dirt to prevent weld contamination.

To begin arc welding, the filler metal is touched to the work and quickly withdrawn a short distance (enough to maintain the proper arc). To maintain the arc, the filler metal should be fed continuously into the molten weld pool to compensate for metal deposited, and moved rapidly and continuously in the direction of welding. To finish the weld or break the arc, the filler metal should be held close to the work to shorten the arc, then moved quickly back over the finished bead. To reduce weld oxidation and porosity, the arc should be kept as short as possible during welding. Too long an arc is inefficient and increases spattering.

After welding, all slag and scale should be completely removed from the weld bead and the adjacent base metal. Scale or oxide can be removed by grinding, pickling, or sandblasting. Discoloration (heat tint) should be removed if required in the specification. Light weld discoloration may be removed electrolytically. When grinding, refinish with progressively finer grits.

The smoother and cleaner the surface of any stainless part, the better the corrosion resistance.

When welding a butt joint in flat position, the current selected should be high enough to ensure ample penetration with good wash-up on the sides. When several beads are required, use a number of small weld beads to fill the groove, rather than one or two large beads.

When welding stainless steel, use a short arc with only a slight weaving motion.

A short arc should be maintained, and any weaving should be limited to 2½ times the filler metal diameter. The filler metal should be held vertical or slightly tilted in the direction of travel. A very slight tilt is only used with small-diameter filler metals. In general, the correct filler metal position is one that produces a clean weld pool that solidifies uniformly as the work progresses. The movement of the filler metal across the weld pool controls the flow of metal and slag. A crescent weave bead should be used.

Horizontal fillet welds and lap welds require a machine setting high enough to provide a well-shaped bead and penetration to the root of the joint. If too low a current is used, it is difficult to control the arc in the joint, and a convex bead with poor fusion results.

When two workpieces of equal thickness are being welded, the filler metal should be held an equal distance from each face and tilted slightly in the direction of travel. If one workpiece is thinner than the other, the filler metal should be pointed toward the thicker workpiece.

In uphill welding of stainless steel, avoid any whipping action of the filler metal. Instead, use a motion in the form of a V.

Welding butt joints in uphill position can be accomplished with a reduced current compared to that used in flat position for a given filler metal diameter. Oscillating and whipping motions are not recommended but instead a motion in the form of a V may be used for the first pass. The point of the V is the root of the joint. Hesitating momentarily at the V ensures adequate penetration and allows slag to move to the surface. The arc is then brought out on one side of the V about ⅛″ and immediately returned to the root of the joint.

After the pause at the root, the procedure is repeated on the other side of the weld. Filler metals with a diameter of 3/16″ may be used on workpieces thick enough to rapidly dissipate heat, but 5/32″ diameter filler metals are the generally accepted maximum size for thin workpieces.

Stringer beads are recommended when welding in overhead position, since attempts to carry a large molten weld pool result in an irregular convex bead. The welding machine should be set properly and a short arc maintained to provide good penetration of the base metal.

Specific Welding Considerations for Stainless Steels

Specific welding conditions for stainless steels are dictated by the specific alloy family. The type of steel welded will influence factors such as heat input during welding, preheat, and postheating.

When exposed to high heat, stainless steels produce chromium carbides at grain boundaries in the HAZ, which is known as sensitization. *Sensitization* is precipitation of chromium carbides in stainless steels from exposure to high temperatures, as in welding, typically in the HAZ. Sensitization occurs in ferritic stainless steels, austenitic stainless steels, cast stainless steels, and nickel alloys. Sensitization increases susceptibility to corrosion and leads to loss of corrosion resistance by making less chromium available to contribute to the protective corrosion-resistant surface film. The temperature at which sensitization occurs depends on the type of alloy welded. See Figure 41-10.

Martensitic Stainless Steels. Martensitic stainless steels are weldable except for type 416 Se, which contains selenium to make it free-machining. The hardness of the HAZ and the corresponding susceptibility to hydrogen

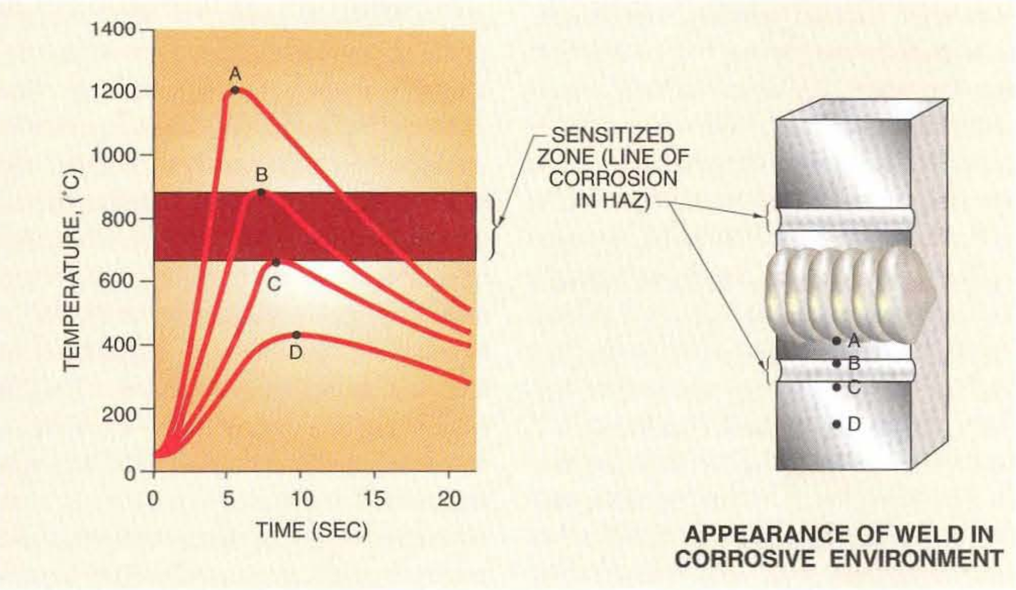


Figure 41-10. *Sensitization is the precipitation of chromium carbides in the HAZ of the weld in stainless steels and iron-chromium alloys, which leads to loss of corrosion resistance in certain chemical environments.*

cracking increase as the carbon content of martensitic stainless steels increases. Martensitic stainless steels require preheat, interpass temperature control, and postheating. Preheat and interpass temperatures are from 450°F (232°C) to 550°F (287°C). Precautions must be taken to prevent the introduction of hydrogen into the weld. The preheat temperature range indicated is not sufficiently high to prevent martensite formation or to reduce the hardness of the HAZ, so that postheating must be performed immediately to toughen the martensite and reduce residual stresses. Postheating is conducted between 1200°F (649°C) and 1400°F (760°C), followed by slow cooling.

When welding martensitic stainless steels such as types 403, 410, 414, and 420, type 410 filler metal is used. When matching carbon content is desired, type 420 may be welded with type 420 filler metal.

Austenitic stainless steel filler metals such as types 308, 309, or 310 are also used to weld martensitic stainless steels. These filler metals provide good as-welded toughness when a high-strength weld deposit is not required. Weld beads of these filler metals may be used when preheat and postheating are not possible.

Assistance in selecting the proper filler metal for a particular welding operation can be found in documents published by the American Welding Society. AWS A5.01, Filler Metal Procurement Guidelines, *and FMC,* Filler Metal Comparison Charts, *are two useful references published by AWS.*

Ferritic Stainless Steels. Ferritic stainless steels are weldable except for type 430F, which contains sulfur to make it free-machining. Ferritic stainless steels do not harden on quenching and do not require preheat. However, preheat between 300°F (149°C) and 450°F (232°C) may be beneficial in reducing residual stress in highly restrained joints. Postheating is unnecessary.

If the service application requires it, ferritic stainless steels must be solution annealed after welding to redissolve chromium carbides and restore corrosion resistance. Solution annealing is carried out between 1400°F (760°C) and 1500°F (815°C), and is followed by rapid quenching.

Grain growth is a problem with all ferritic stainless steels, particularly the subgroup of low-interstitial ferritic stainless steels. Grain growth occurs in the HAZ during welding, leading to loss of toughness. Grain growth is minimized by limiting the interpass temperature to the lowest practical level

above the preheat temperature. Toughness can be improved by cold working the weld. Ferritic stainless steels with high chromium content, such as types 430, 434, 442, and 446, form chromium carbides and sensitize at grain boundaries in the HAZ.

Ferritic stainless steels can be arc welded by GTAW, GMAW, and FCAW. Welding processes that tend to increase carbon pickup are not recommended. This would include OFW, carbon arc, and GMAW with CO_2 shielding gas.

Matching ferritic stainless steel, austenitic stainless steel, and nickel alloy filler metal are used. Matching ferritic stainless steel filler metals are commonly available as type 409 and type 430, and are available as solid and flux cored electrode.

Ferritic stainless steels can be joined to themselves or to other metals using austenitic stainless steel filler metals. Type 309 and type 310 stainless steel are most often used. Nickel alloy filler metals such as ENiCrFe-3 can also be used (with SMAW). The advantage of austenitic stainless steel filler metals and nickel alloy filler metals is better as-welded toughness than matching ferritic stainless steel filler metals.

Austenitic Stainless Steels. Austenitic stainless steels are weldable except for type 303 and type 303Se, which contain sulfur and selenium, respectively, to make them free-machining. Austenitic stainless steels do not harden on quenching and do not require preheat or postheating to improve their mechanical properties. However, cold-worked austenitic stainless steel will lose strength in the HAZ when welded.

Austenitic stainless steels are susceptible to hot cracking. A completely austenitic metallurgical structure possesses insufficient ductility when solidifying from the molten state and may hot crack from an inability to accommodate shrinkage stress. Thus, filler metals used to weld austenitic stainless steels must have modified chemical compositions to produce a small amount of ferrite in the metallurgical structure, which counteracts hot cracking. The chemical composition adjustment is indicated by the ferrite number of the filler metal. Filler metal suppliers indicate a ferrite number (FN) on electrodes and wire used for welding austenitic stainless steels. A ferrite number between 2FN and 12FN is required when welding austenitic stainless steels. The lower the FN, the less the amount of ferrite. Ferrite makes a weld slightly magnetic.

Austenitic stainless steels can be welded using most arc welding processes, including GMAW, GTAW, SMAW, FCAW, PAW, and SAW. OFW is infrequently used, but may be used when arc welding equipment is not available. In general, the deposited weld metal composition should nearly match the base metal composition when welding austenitic stainless steels to themselves. Other austenitic stainless steel filler metals may be used provided the selected filler metal has suitable corrosion resistance, mechanical properties, or both. Alternate filler metals are usually more highly alloyed than the base metal to provide superior corrosion resistance.

Consumable inserts are available for welding austenitic stainless steels. They are used as preplaced filler metal in the root opening for the first weld pass, and are completely fused into the root of the joint. Consumable inserts should not be used where the presence of a crevice between the insert and the base metal creates a condition for corrosion.

Austenitic stainless steels require less heat input and less current than carbon steel because of their lower melting point and higher electrical resistivity. Their high coefficient of thermal expansion coupled with low thermal conductivity increases the possibility for distortion and warpage. When welding austenitic stainless steels less than ¼″ thick, distortion or warpage may

be a serious problem. Rigid fixturing of the workpieces can help control distortion of thin sheets during welding. Metals more than ¼″ thick may require special welding techniques to counteract distortion. Back-step welding and intermittent welding help overcome the problems of distortion and warpage.

Stress relief heat treatment is not recommended for austenitic stainless steels. Stress relief heat treatment between 1200°F (649°C) and 1600°F (871°C) can result in significant distortion and loss of corrosion resistance from sensitization. However, a low-temperature stress relief heat treatment between 400°F (204°C) and 800°F (427°C) helps improve dimensional stability and helps reduce peak stresses, but does not reduce corrosion resistance. This heat treatment is sometimes performed on items that must be straight, such as shafts, by suspending them vertically at temperature for many hours.

With austenitic stainless steels, sensitization occurs between 800°F (427°C) and 1500°F (816°C), and most rapidly above 1200°F (649°C). When heated to the sensitization temperature range, carbon and chromium in the alloy combine to form chromium carbide, reducing corrosion resistance.

To prevent sensitization when welding austenitic stainless steels, low-carbon stainless steel grades or dual-marked stainless steel grades are used. Low-carbon grades have the suffix letter L in their designation, for example 304L or 316L. Their carbon content is reduced to prevent chromium carbide precipitation during the temperate-time cycle of welding operations. Dual-marked stainless steels such as 304/304L or 316/316L are also low in carbon to prevent sensitization, but contain nitrogen to counteract the strength loss from the lower carbon content. Dual-marked stainless steels exhibit the superior mechanical properties of the higher carbon grade and the superior corrosion resistance of the lower carbon grade. Another method of preventing sensitization is to use austenitic stainless steels, such as 321 and 347, which contain alloying elements that counteract the formation of chromium carbide and are resistant to sensitization.

Duplex Stainless Steels. Welding of duplex stainless steels can upset the balance of austenite and ferrite, leading to loss of corrosion resistance and loss of toughness in the HAZ. The welding procedure must not allow an imbalance by increasing the ferrite content of the HAZ. To prevent problems, weld with low heat input and control the cooling rate. Low heat input minimizes dwell time in the "red heat" temperature zone. Controlling the cooling rate prevents the formation of excessive ferrite (with rapid cooling) or excessive austenite (with slow cooling). The maximum interpass temperature should be 240°F (116°C) for thin metal and 300°F (149°C) for thick metal, to promote the proper cooling rate. Preheat and postheating are not usually performed on duplex stainless steels.

Duplex stainless steels can be welded using any arc welding process. Duplex stainless steels should always be welded with filler metal added. Without filler metal, the weld and the HAZ contain too much ferrite and the joint properties are inadequate. Autogenous welds should not be used. Matching filler metal is usually recommended. In some cases filler metals with more chromium and molybdenum than the base metal may be used to enhance corrosion resistance. For each welding job and type of duplex stainless steel, it is necessary to develop the appropriate welding procedure and technique.

Precipitation Hardening Stainless Steels. Martensitic and semi-austenitic precipitation hardening stainless steels are weldable without preheat. Austenitic precipitation hardening stainless steels are susceptible to hot cracking and have poor weldability. If maximum

strength is required in martensitic and semi-austenitic precipitation hardening stainless steels, matching filler metal is required and the complete heat treatment cycle must be repeated. If the complete cycle cannot be repeated, the parts should be solution annealed before welding and precipitation hardened after. For martensitic precipitation hardening stainless steels, a repeat of the precipitation hardening after welding may be adequate to restore mechanical properties.

If full strength is not required, ductile 309 or 310 austenitic stainless steel or nickel alloy filler metal may be used on martensitic precipitation hardening stainless steels. Follow manufacturer instructions when welding precipitation hardening stainless steels. Nickel alloy or austenitic stainless steel filler metals are normally used for welding austenitic precipitation hardening stainless steels.

The Lincoln Electric Company

Stainless steel weldability varies depending on the metallurgical structure. Service requirements of the stainless steel must be considered when developing welding procedures.

Cast Stainless Steels. Weldability of cast stainless steels varies according to their metallurgical structure; guidelines for the corresponding wrought alloys should be followed. Cast stainless steels are usually welded to repair casting defects or damage from service. Heat-resistant cast stainless steels that have been in service at elevated temperatures tend to lose ductility and may crack during welding. High-temperature solution annealing heat treatment at 2000°F (1093°C) should be performed prior to welding to restore as-cast ductility. Solution annealing dissolves alloy carbides that precipitate during service at elevated temperature and cause the reduction in ductility.

Regular carbon grades of corrosion-resistant cast stainless steels that require remedial welding to repair casting defects must be solution annealed after welding to fully restore corrosion resistance. Regular carbon grades that include CF-8 or CF-8M sensitize on welding. Solution annealing of finish-machined castings may lead to distortion so that remedial welding must be carried out before final machining.

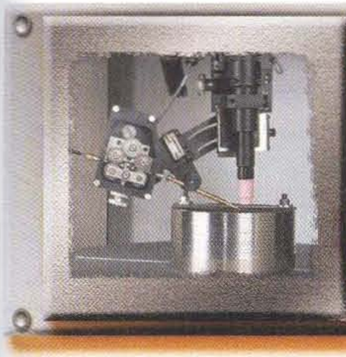
Cast stainless steels are more prone to hot cracking than cast steel so the weld bevel angle should be wider than that used for cast steels. It is common to have a bevel angle up to 90° for cast stainless steels versus the 45° that is common for cast steels. Low heat input also helps reduce hot cracking. Because of the tendency of cast stainless steels toward hot cracking, it may be necessary to butter the weld bevel for certain types of repairs.

POINTS TO REMEMBER

1. Stainless steels are used for their heat resistance, corrosion resistance, and low-temperature toughness.
2. Wrought stainless steels are usually identified by a three-digit AISI designation, such as 410 or 316.
3. When welding stainless steels, using chill plates made of copper helps conduct heat away from the weld area, reducing the unfavorable effects of heat on the alloy.
4. Heat tint may cause a slight overall chromium depletion in the surface film, but it does not usually compromise the ability of the surface film to provide corrosion resistance.
5. When welding stainless steel, use a short arc with only a slight weaving motion.
6. In uphill welding of stainless steel, avoid any whipping action of the filler metal. Instead, use a motion in the form of a V.

QUESTIONS FOR STUDY AND DISCUSSION

1. How are stainless steels classified?
2. What are the qualities of stainless steel that make this metal so valuable?
3. Why are chill plates frequently used when welding stainless steel?
4. Why is less current required in welding stainless steel?



Weldability of Nonferrous Metals 42

Welding Technology

Nonferrous metals include nickel alloys, copper alloys, aluminum alloys, magnesium alloys, and titanium alloys. Nickel is incorporated as a major or minor constituent in approximately 3000 alloys. Nickel alloys are generally easy to weld provided the joint is clean. Copper alloys are wrought or cast and consist of several families of alloys. Copper and copper alloys are difficult to weld because of their high thermal conductivity, high coefficient of thermal expansion, hot cracking susceptibility, and high fluidity.

Aluminum alloys can be wrought or cast, and contain various elements added to produce alloys with specific properties. Aluminum alloys are generally easy to weld. Magnesium is the lightest commercial metal and is alloyed with many chemical elements. This results in high strength-to-weight ratio metals that are easy to weld. Titanium alloys are grouped according to their metallurgical structure and are difficult to weld because of the need for high purity.

WELDABILITY OF NICKEL ALLOYS

Nickel is incorporated as a major or minor constituent in approximately 3000 alloys. The principal alloying elements added to nickel are copper, iron, molybdenum, chromium, and cobalt. See Figure 42-1. The major nickel alloy systems are based on nickel and nickel-chromium. Nickel alloys have an austenitic structure and behave similarly to austenitic stainless steels in many ways. Nickel alloys are strengthened by cold working or precipitation hardening and may be heat-treated to improve corrosion resistance.

General Welding Considerations for Nickel Alloys

Weldability factors for nickel alloys include joint cleanliness, distortion, heat requirements, welding processes, and filler metals.

Joint Cleanliness. Joint cleanliness is the single most important requirement for welding nickel alloys. Nickel alloys are extremely sensitive to cracking from contamination. Sulfur, present in grease and oil, is particularly harmful to nickel. Oxides can inhibit wetting, prevent fusion of the base metal and filler metal, and can cause subsurface inclusions and poor bead contour. A region approximately 1″ on both sides of the joint should be thoroughly degreased to prevent contamination by sulfur, and mechanically cleaned to remove oxides before welding. Mechanical cleaning is accomplished by grinding, abrasive blasting, or machining and pickling.

Distortion. Distortion is possible in nickel alloys because of their relatively low thermal conductivity. Low thermal conductivity causes heat to be retained in the weld rather than be dissipated into the base metal. The exception is

Nickel alloys are extremely sensitive to cracking from contamination, and the joint must be thoroughly cleaned before welding.

Nickel Alloy Families
Figure 42-1

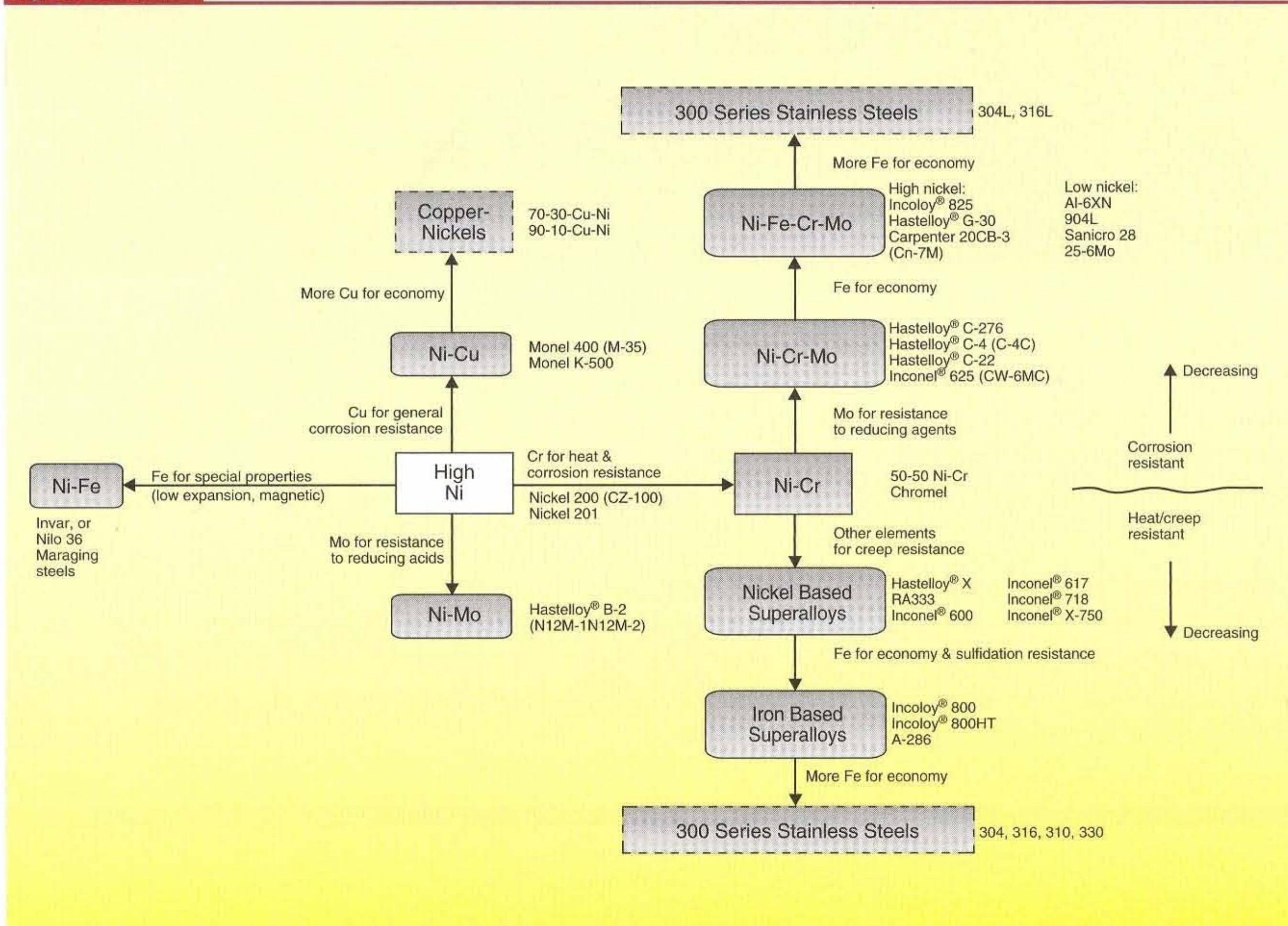


Figure 42-1. *Nickel is incorporated as a major or minor constituent in approximately 3000 alloys.*

commercially pure nickel, which has relatively high thermal conductivity. However, since the coefficients of thermal expansion of nickel alloys are similar to those of carbon steels and low-alloy steels, the welding of nickel alloys does not present significant distortion problems. Nickel-iron alloys are an exception because they have very low coefficients of thermal expansion.

Heat Requirements. Since nickel alloys are sensitive to high heat input, low heat input should be used when welding nickel alloys. High heat input can lead to hot cracking, loss of corrosion resistance, or both. If hot cracking is anticipated, such as might occur in a highly restrained joint, the welding technique is modified to decrease heat input, or a welding process with lower heat input is substituted. Preheat is not required for nickel alloys; however, the joint area is heated to about 60°F (16°C) to eliminate moisture condensation that could lead to porosity. The interpass temperature should be low to minimize total heat input. Cooling methods that reduce the interpass temperature should not introduce contaminants that cause weld metal cracking.

Postheating is not required to restore mechanical properties, except for precipitation hardening alloys. Alloys that sensitize when welded may require postheating consisting of solution annealing and quenching to restore corrosion resistance.

Welding Processes. Almost all arc welding processes can be used for welding nickel alloys; however, SMAW, GTAW,

and GMAW are the most common processes used. Not all arc welding processes are applicable to every alloy because of metallurgical characteristics and/or availability of suitable filler metals. OFW should only be used when arc welding equipment is not available. The welding of nickel alloys is similar to the welding of austenitic stainless steels except that cleanliness requirements are more stringent and groove openings are increased to allow for the lower penetration of nickel alloys.

Filler Metals. Filler metals for welding nickel alloys should have a chemical composition that is similar to the base metal. Covered filler metals for SMAW normally contain additions of deoxidizing elements such as titanium, manganese, and columbium to prevent weld metal cracking.

Precipitation hardenable filler metal will respond to the precipitation hardening treatment used for the base metal. However, the response is usually less pronounced and the weld joint is generally lower in strength than the base metal after the precipitation hardening treatment.

Fluxes are available for SAW for many nickel alloys. The flux composition must be suited to both the filler metal and the base metal. An improper flux can cause slag adherence, inclusions, poor weld bead contour, and undesirable changes in weld metal composition.

Welding Monel® and Inconel®

Monel® and Inconel® are trademarks for two groups of nickel alloys. When used without qualification, they refer to alloy 400 (Monel® alloy 400) or alloy 600 (Inconel® alloy 600). Monel® and Inconel® can be satisfactorily welded using SMAW. Welding of Monel® and Inconel® is performed almost as easily as welding low-carbon steel. Although Monel® and Inconel® can be welded in any position, better results are obtained if welded in flat position. In general, SMAW should not be used on sheet less than .050″ (18-gauge) thick; GTAW is best used on thin gauges. No preheat is necessary to weld Monel® or Inconel®. The procedure for welding Monel® or Inconel® is as follows:

1. Remove the thin, dark-colored oxide film from around the area to be welded. The oxide can be removed by grinding, sandblasting, rubbing with emery cloth, or pickling.
2. Use a heavily coated filler metal specially designed for welding Monel® and Inconel®. Use DCEP current.
3. Hold the filler metal at a travel angle of about 20° from the vertical and ahead of the weld pool when welding in flat position, as it is easier to control the molten flux and to estimate slag trappings. To make welds in other positions, hold the filler metal at approximately a right angle to the workpiece.
4. Withdraw the filler metal slowly from the crater to permit a blanket of flame to cover the crater, protecting it from oxidation while the metal solidifies.
5. Use a minimum of weaving to prevent depositing wide weld beads.

Remove the oxide film from the surface to be welded and use heavily coated filler metal specially designed for Monel® and Inconel®.

WELDABILITY OF COPPER ALLOYS

Copper can be combined with many elements to produce various alloys. Copper alloys can be strengthened by cold working or precipitation hardening and generally possess good thermal and electrical conductivity, which affect their weldability.

Copper alloys are wrought or cast and consist of commercially pure coppers, modified coppers, beryllium coppers, brasses, tin bronzes, aluminum bronzes, copper-nickels, and nickel-silvers. See Figure 42-2. Many copper alloys have leaded equivalents, which contain a small amount of lead to improve their machinability.

Commercially pure coppers are wrought or cast. Wrought commercially pure coppers contain at least 99.9% copper. They are used primarily for their

Commercially pure coppers are wrought or cast and are used primarily for their high electrical conductivity.

high electrical conductivity. Cast commercially pure coppers have lower electrical and thermal conductivity than equivalent wrought alloys because the elements that must be added to ensure a sound casting, such as silicon, decrease conductivity. Commercially pure coppers are soft, weak, and very ductile. They include oxygen-free coppers, deoxidized coppers, and tough pitch coppers.

Beryllium coppers are wrought and cast copper alloys that contain small amounts of beryllium. Beryllium coppers are precipitation hardened to extremely high levels of tensile and fatigue strength, comparable to low-alloy steels. Small amounts of cobalt or nickel may be added to refine the grain size.

Brasses are wrought alloys of copper and zinc, with 5% to 50% zinc content. Some brasses also contain other elements. Brasses are the most popular and least expensive of the copper alloys. They display a wide range of mechanical properties, are easy to work, have a pleasing color, and exhibit good corrosion resistance. Brasses consist of alpha and beta brasses, tin brasses, and leaded brasses.

Casting brasses contain specific alloying elements to improve their castability and strength beyond that of regular wrought brasses. They consist of combinations of tin, lead, iron, manganese, aluminum, and nickel. Casting brasses can be poured into complex shapes with low porosity and good mechanical properties.

Copper Alloy Families
Figure 42-2

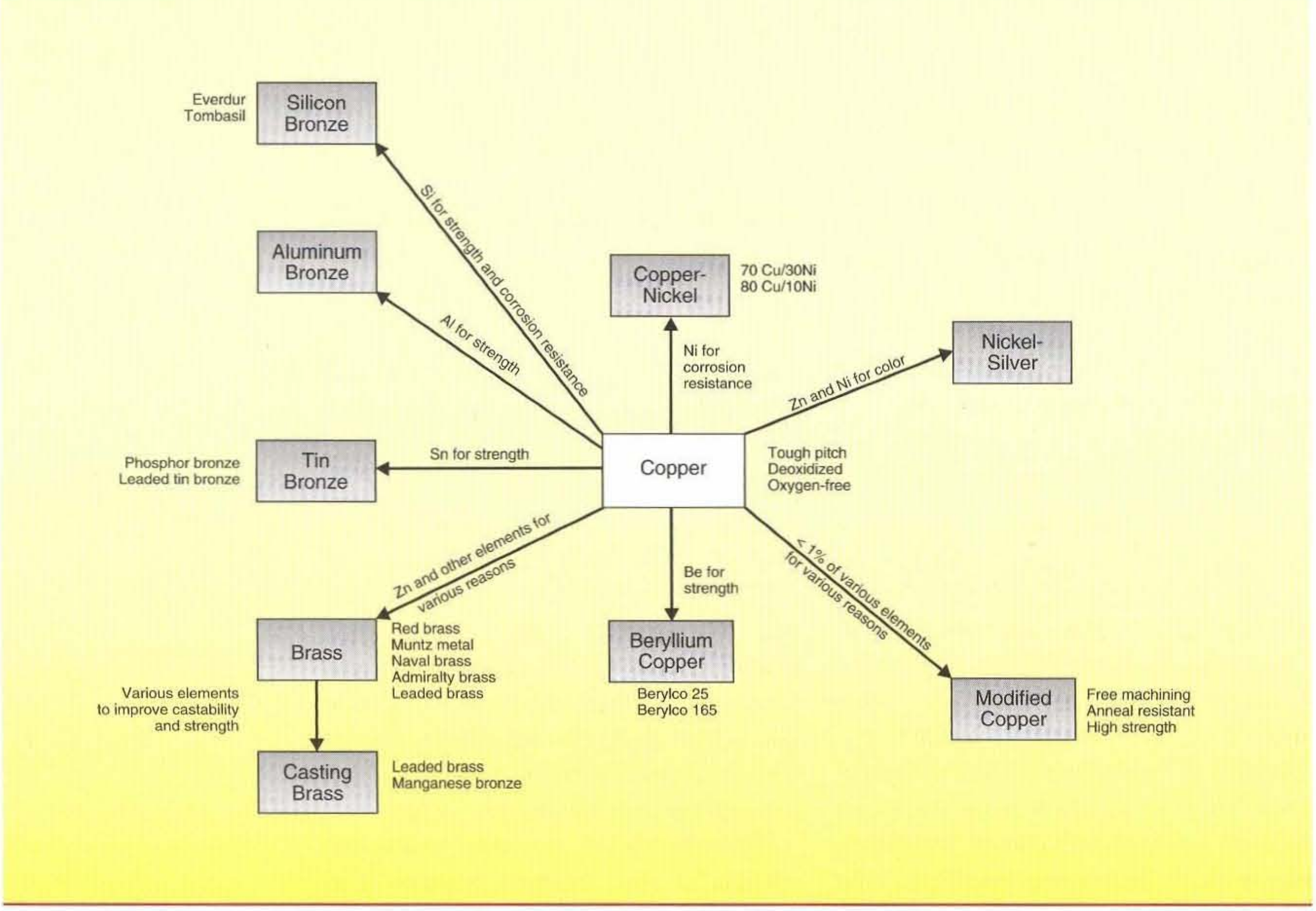


Figure 42-2. *Many copper alloys have leaded equivalents that contain a small amount of lead to improve their machinability.*

Tin bronzes (phosphor bronzes) are wrought and cast alloys of copper and tin. Tin bronzes contain from 1.25% to 10% tin, plus lead, zinc, nickel, and phosphorus. Phosphorus can be added as a deoxidizer in castings to improve soundness and cleanliness. Tin bronzes have high strength, good toughness, high corrosion resistance, and a low coefficient of friction, making them suitable for bearings operating under high loads.

Aluminum bronzes are wrought and cast alloys of copper that contain between 7% and 13.5% aluminum, plus small amounts of manganese, nickel, and iron. Aluminum bronzes have good strength and excellent corrosion and wear resistance. Nickel is added to aluminum bronzes to further improve corrosion resistance. Aluminum bronzes are used for bushings and corrosion-resistant parts.

Silicon bronzes are wrought and cast alloys of copper that contain between 1% and 5% silicon and additions of manganese, iron, and zinc. Some wrought and cast silicon bronzes have leaded equivalents. Silicon bronzes have high strength similar to carbon steel, good toughness, and excellent corrosion resistance. They are used for bearings, and pump and valve components.

Copper-nickels are wrought and cast alloys of copper containing up to 30% nickel, plus minor additions of iron, chromium, tin, or beryllium. Iron is added for increased resistance to erosion-corrosion in water. *Erosion-corrosion* is the detrimental effect of velocity or turbulence in a corrosive environment. Copper-nickels have moderate strength and better corrosion resistance than other copper alloys. They are used for seawater components.

Copper is resistant to oxidation, moisture, and some organic chemicals, making it useful for electrical conductors, water tubing, heat exchangers, and chemical equipment.

Thermadyne Industries, Inc.

Copper tubing has high thermal conductivity and is commonly joined by sweat soldering.

Nickel-silvers are wrought and cast alloys of copper that contain between 5% and 45% zinc, and from 5% to 30% nickel. Nickel has a strong decolorizing effect on copper-zinc alloys (brasses). With greater than 20% nickel, the color turns to silver-white and the alloy takes on a brilliant polish. Nickel-silvers are used for valve trim, zippers, and camera parts.

General Welding Considerations for Copper Alloys

Copper and copper alloys are difficult to weld because of their high thermal conductivity, high coefficient of thermal expansion, hot cracking susceptibility, and high fluidity. *Fluidity* is a measure of the viscosity or flowability of a liquid or molten solid. Leaded copper and copper alloys should not be welded because the lead creates porosity and promotes cracking within a weld.

Welding Processes. Most arc welding processes as well as OFW can be used to weld copper alloys. The low heat input of the oxyacetylene flame makes OFW a relatively slow process compared with arc welding. Coppers and certain high-copper alloys are very difficult to resistance spot and seam weld because of their high electrical and thermal conductivities. Copper alloys can be readily joined by brazing and soldering.

Filler Metals. Copper alloys are generally welded with matching filler metals. Filler metals that can be used to weld copper alloys include covered and bare filler metal. These may be used to weld copper alloys to themselves or to other metals. Many of these filler metals meet AWS classifications. Silver alloys and copper-phosphorus filler metals are most commonly used for brazing copper alloys. See Figure 42-3.

Specific Welding Considerations for Copper Alloys

Silicon bronzes have relatively low thermal conductivity and only require preheat when joint thickness is more than 2″. Aluminum bronzes are susceptible to hot cracking, especially with less than 7% aluminum. Alloys with higher aluminum content are weldable with adequate preheat. Copper-nickels have thermal and electrical conductivities similar to carbon steel and are relatively easy to weld. Cleanliness is essential and preheat is not required. Nickel-silvers are similar to brasses because of their high zinc content and should be brazed rather than welded.

Commercially Pure Coppers. Commercially pure coppers require preheat from 250°F (121°C) to 1000°F (538°C), depending on joint thickness. High-strength anneal-resistant coppers are welded with less preheat than is required for other commercially pure coppers to preserve their strength.

Figure 42-3. *Filler metals that can be used to weld copper alloys include covered and bare filler metal and bare rods. Many of these filler metals meet AWS classifications.*

FILLER METALS FOR WELDING COPPER ALLOYS

Base Metal	Name	Covered*	Bare†
Copper	Copper	ECu	ERCu
Silicon Bronzes, Brasses	Silicon Bronze	ECuSi	ERCuSi-A
Phosphor Bronzes, Brasses	Phosphor Bronze	ECuSn-A	ERCuSn-A
Phosphor Bronzes, Brasses	Phosphor Bronze	ECuSn-C	ERCuSn-A
Copper-Nickels	Copper-Nickel	ECuNi	ERCuNi
Aluminum Bronzes, Brasses, Silicon Bronzes, Manganese Bronzes	Aluminum Bronze	ECuAl-A2	ERCuAl-A1 ERCuAl-A2
Aluminum Bronzes	Aluminum Bronze	ECuAl-B	ERCuAl-A3
Nickel-Aluminum Bronzes	—	ECuNiAl	ERCuNiAl
Manganese-Nickel-Aluminum Bronzes	—	ECuMnNiAl	ERCuMnNiAl
Brasses, Copper	Naval Brass	—	RBCuZn-A
Brasses, Manganese Bronzes	Low-fuming Brass	—	RBCuZn-B
Brasses, Manganese Bronzes	Low-fuming Brass	—	RBCuZn-C
Nickel-Silvers	—	—	RBCuZN-D

* ANSI/AWS A5.6, *Specification for Covered Copper and Copper Alloy Arc Welding Electrodes*
† ANSI/AWS A5.7, *Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes.* ANSI/AWS A5.8, *Specification for Filler Metals for Brazing and Braze Welding*

Oxygen-free coppers are welded as rapidly as possible to minimize oxygen pickup. Deoxidized coppers are the most commonly used type of copper for fabrication by welding. Deoxidized copper is susceptible to oxygen pickup and requires silicon-containing filler metal to minimize the effects of oxygen pickup. Since copper has a very high coefficient of expansion, precautions must be taken to prevent contraction of the joint. Jigs and fixtures must be used to prevent movement during cooling. However, even when jigs are used, contraction forces can cause cracking during cooling.

Special coated metal arc filler metals have been developed to weld sheet copper. The most common are phosphor bronze (ECuSn-A) and aluminum bronze (ECuAl-A). The joint design used for deoxidized coppers must include a relatively large root opening and groove angle. Tight joints should be avoided to prevent buckling, poor penetration, slag inclusions, undercutting, and porosity. Copper backing strips are often advisable.

Tough pitch coppers contain a uniform distribution of copper oxide, which is insufficient to affect ductility, but can cause problems when welding. When heated above 1680°F (916°C) for prolonged periods, the copper oxide tends to migrate to the grain boundaries, leading to a reduction in strength and ductility. Additionally, the copper absorbs carbon monoxide and hydrogen, which react with the copper oxide and release carbon dioxide and water vapor. Carbon dioxide and water vapor are not soluble in copper and exert pressure between the grains, producing internal cracking and embrittlement.

Tough pitch coppers are not recommended for gas welding because gas welding causes embrittlement; brazing or soldering should be used. However, some welds can be made with SMAW in situations where tensile strength requirements are extremely low (19,000 psi or less), provided a high welding current and high travel speed are used. The high current and travel speed do not allow embrittlement to develop.

⚠ WARNING

When welding brass, ensure proper ventilation of the work area to remove harmful zinc oxide fumes.

Beryllium Coppers. Beryllium coppers form an oxide film that inhibits wetting and fusion during welding. An absolutely clean joint surface is required and may be achieved by abrading the surface. Beryllium coppers are welded in the soft annealed condition and then precipitation hardened to achieve the required strength.

Brasses. Since the application of heat tends to vaporize zinc, arc welding on brass is difficult. When zinc volatilizes, the zinc fumes and oxides often obscure vision and make welding hard to perform. Furthermore, the formation of oxides produces a dirty surface that ruins the wetting properties of the molten metal. To arc weld brasses, use heavily coated phosphor-bronze filler metals and make small deposits of metal. Preheat should be eliminated and a lower welding current used.

Use heavily coated phosphor-bronze filler metals when welding tin bronze and make small deposits of beads at a time.

Zinc vapors can be minimized by decreasing or eliminating preheat, or by using lower welding currents. High-zinc brasses have lower thermal conductivity and require less preheat than low-zinc brasses.

Tin Bronzes. Since the thermal conductivity of tin bronze is similar to that of steel, it can be easily welded. When using SMAW, a heavily coated phosphor-bronze filler metal should be used, with DCEP current. The metal must be absolutely clean to ensure a sound weld.

Tin bronzes are very susceptible to hot cracking. To prevent hot cracking, tin bronzes should be preheated to between 300°F (149°C) and 400°F (204°C). High welding currents and high travel speeds are used and each weld pass is peened.

⚠ CAUTION

To keep airborne concentrations of beryllium within allowable limits, proper safety precautions must be taken when melting, welding, flame cutting, polishing, buffing, grinding, and machining beryllium coppers.

WELDABILITY OF ALUMINUM ALLOYS

Aluminum alloys can be wrought or cast. Various elements are added to aluminum to produce alloys with specific properties. Aluminum alloys can be strengthened by work hardening or precipitation hardening. The weldability of aluminum alloys is influenced by cleanliness requirements, heat requirements, and desired appearance.

Aluminum alloys have low density, good corrosion resistance, and good weldability. Cold-worked alloys suffer a loss of strength in the HAZ during welding. Precipitation hardened alloys must be heat-treated after welding to restore their strength.

Aluminum alloys consist of various families (series) of wrought or cast alloys. Each series is identified by a sequence of numbers. For example, wrought aluminum manganese alloys are identified by the 3XXX series, such as alloy 3003. Cast aluminum-silicon alloys are identified by the 3XX.X series, for example alloy 356.0. See Figure 42-4.

Temper designations are alphanumeric notations that indicate the final condition of cold-worked (H) or heat-treated (T) metal. A number following the letter indicates the condition. Temper designation is separated from the alloy identification number by a hyphen. For example, 3003-H2 designates quarter hard aluminum manganese alloy.

General Welding Considerations for Aluminum Alloys

General welding considerations for all aluminum alloys include appearance, cleaning requirements, heat requirements, welding processes, and filler metals.

Aluminum Alloy Families
Figure 42-4

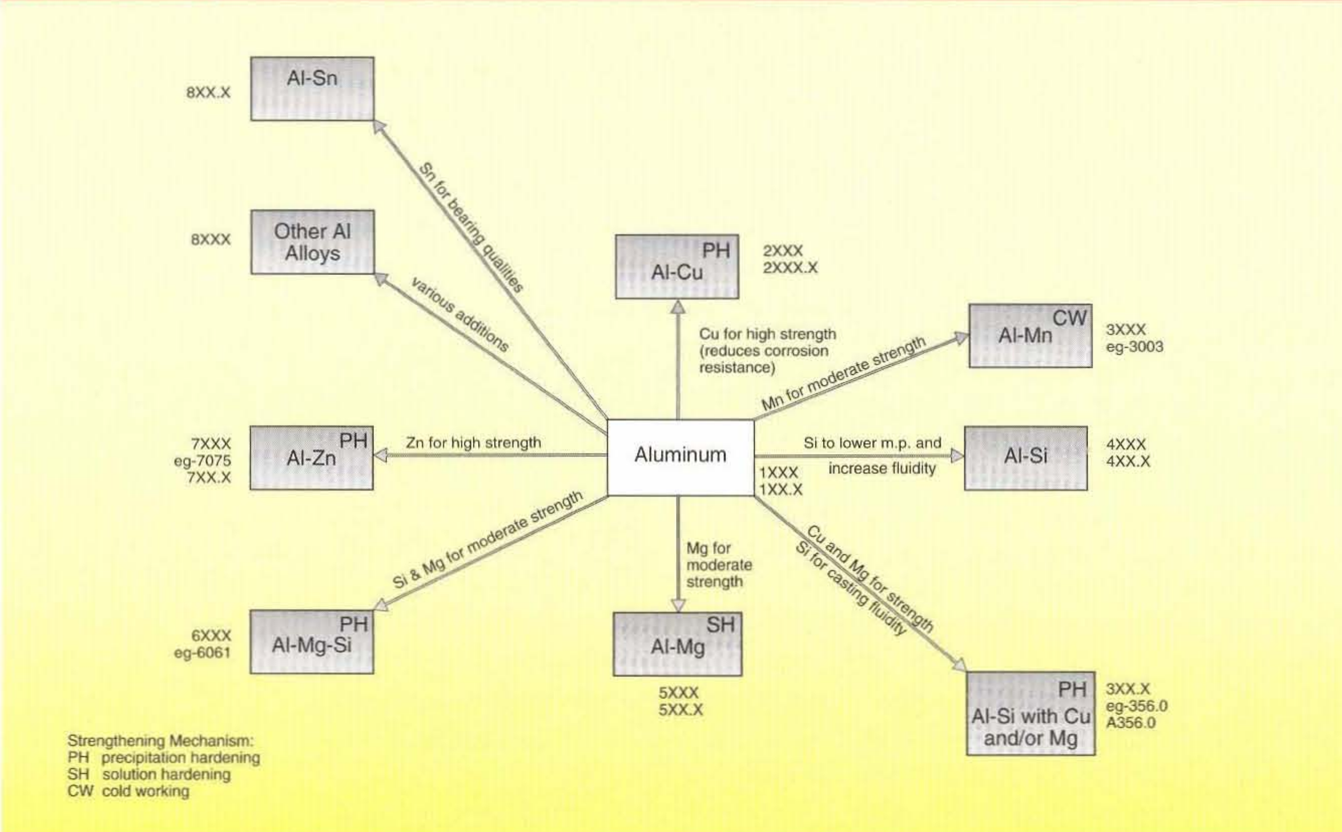


Figure 42-4. *Aluminum alloys consist of various families (series) of wrought or cast alloys, each of which is identified by a sequence of numbers.*

Appearance. The appearance of aluminum after welding is often of great importance. GMAW and GTAW can provide the best as-welded bead appearance. Welded parts may be given a chemical or electrochemical (anodic) surface treatment to provide corrosion resistance, coloring, or both. All flux must be removed from brazed, soldered, or welded joints prior to surface treatment. Filler metals that contain a large amount of silicon darken during anodic treatment.

Cleaning Requirements. Cleaning requirements for aluminum alloys are stringent because, during welding, the naturally formed aluminum oxide surface film thickens and becomes a hindrance. The surface film must be removed before fusion or resistance welding, and must be prevented from re-forming by means of an inert gas shield or by pressure between the joint surfaces. If the surface film is not removed, small particles of unmelted oxide will be trapped in the weld, causing a reduction in ductility, lack of fusion, and weld cracking.

The aluminum oxide surface film may be removed electrically, mechanically, or chemically. Electrical cleaning occurs during welding. The surface film is blasted away by cathodic bombardment during the positive half-cycle of the sine wave, making electrical cleaning a good method of in situ cleaning.

Mechanical cleaning is usually done immediately before welding by scraping the surface using a clean stainless steel wire brush with light pressure to prevent burnishing or contaminating the surface. Chemical cleaning requires a chemical solution to dissolve the surface film. Chemical attack of the metal must be prevented during cleaning by minimizing exposure time in the solution and, after welding, by immediate removal of residual flux.

Heat Requirements. The high thermal conductivity and high thermal expansion coefficient of aluminum influence its weldability. Aluminum alloys conduct heat three to five times faster than steel so that more heat input is required than for steel, even though the melting point of aluminum is significantly lower than that of steel. Preheat is often required for thick joints, but must not exceed 400°F (204°C) to prevent detrimental effects to the weld joint. High-speed welding processes with high heat input, such as GMAW, are favorable for aluminum welding. The high thermal conductivity of aluminum is beneficial in all-position welding because the rapid cooling of the weld, coupled with its surface tension when molten, results in rapid solidification.

Distortion in aluminum alloys during welding is about twice as great as when welding steel. The amount of distortion is inversely proportional to the speed of welding. Additionally, a volume shrinkage of about 6%, which occurs during solidification, increases the chance of hot cracking in fully restrained joints. Fixtures for welding aluminum alloys must be designed to accommodate both expansion and contraction, and yet maintain the proper geometric position for welding.

Welding Processes. The welding processes commonly used for aluminum are GTAW, GMAW, and resistance welding. GTAW is used for thin joints. AC current is generally used because it provides a cleaning action on the positive half-cycle of the sine wave. Argon is commonly used when welding aluminum and is used at a low flow rate. Helium increases penetration, but a higher flow rate is required. Filler metal must be clean and free of oxide; otherwise, the weld will be porous.

GMAW is applied to thick joints and is much faster than GTAW. Pure argon is normally used for shielding.

The surface film must be removed from aluminum alloys before fusion or resistance welding, and must be prevented from re-forming by means of an inert gas shield or by pressure between the joint surfaces.

The filler metal must be kept clean to prevent porosity. All aluminum alloys may be resistance welded.

Filler Metals. Filler metals for welding aluminum alloys are classified by the same four-digit system used to designate wrought and cast aluminum alloys. Filler metals for joining aluminum alloys fall into the 1XXX, 2XXX, 3XXX, 4XXX, or 5XXX groups. The 1XXX and 4XXX groups are the only two recommended for oxyacetylene welding. Filler metal selection for welding aluminum depends on a number of factors, including base metal composition, strength requirements, ductility requirements, color match after anodizing, corrosion resistance, and cracking tendency. Generally, one type of filler metal usually satisfies several requirements for a specific alloy. See Figure 42-5.

FILLER METALS FOR WELDING ALUMINUM ALLOYS...

Base Metal	Filler Metal Types[a,b,c]								
	201.0, 206.0, 224.0	319.0, 333.0, 354.0, 355.0, C355.0	356.0, A356,0 357.0, A357.0 413.0, 443.0, A440.0	511.0, 512.0, 513.0, 514.0, 535.0	7004, 7005, 7039, 701.0, 712.0	6009, 6010, 6070	6005, 6061, 6063, 6101, 6151, 6201, 6351, 6951	5456	5454
1060, 1070, 1080, 1350	ER4145	ER4145	ER4043[d,e]	ER5356[e,f,g]	ER5356[e,f,g]	ER4045[d,e]	ER4043[e]	ER5356[g]	ER4043[e,g]
1100, 3003, Alc. 3003	ER4145	ER4145	ER4043[d,e]	ER5356[e,f,g]	ER5356[e,f,g]	ER4043[d,e]	ER4043[e]	ER5356[g]	ER4043[e,g]
2014, 2036	ER4145[h]	ER4145[h]	ER4145	—	—	ER4145	ER4145	—	—
2219	ER2319[d]	ER4145[h]	ER4145[e,f]	ER4043[e]	ER4043[e]	ER4043[d,e]	ER4043[d,e]	—	ER4043[e]
3004, Alc. 3004	—	ER4043[e]	ER4043[e]	ER5356[i]	ER5356[i]	ER4043[e]	ER4043[e,i]	ER5356[g]	ER5356[i]
5005, 5050	—	ER4043[e]	ER4043[e]	ER5356[i]	ER5356[i]	ER4043[e]	ER4043[e,i]	ER5356[g]	ER5356[i]
5052, 5652	—	ER4043[e]	ER4043[e,i]	ER5356[i]	ER5356[i]	ER4043[e]	ER5356[f,i]	ER5356[i]	ER5356[i]
5083	—	—	ER5356[e,f,g]	ER5356[g]	ER5183[g]	—	ER5356[g]	ER5183[g]	ER5356[g]
5086	—	—	ER5356[e,f,g]	ER5356[g]	ER5356[g]	—	ER5356[g]	ER5356[g]	ER5356[g]
5154, 5254	—	—	ER4043[e,i]	ER5356[i]	ER5356[i]	—	ER5356[i]	ER5356[i]	ER5356[i]
5454	—	ER4043[e]	ER4043[e,i]	ER5356[i]	ER5356[i]	ER4043[e]	ER5356[f,i]	ER5356[i]	ER5554[h,i]
5456	—	—	ER5356[e,f,g]	ER5356[g]	ER5556[g]	—	ER5356[g]	ER5556[g]	—
6005, 6061, 6101, 6151, 6201, 6351, 6951	ER4145	ER4145[e,f]	ER4043[e,i,j]	ER5356[i]	ER5356[e,f,i]	ER4043[d,e,j]	ER4043[e,i,j]	—	—
6009, 6010, 6070	ER4145	ER4145[e,f]	ER4043[d,e,j]	ER4043[e]	ER4043[e]	ER4043[e,i,j]	—	—	—
7004, 7005, 7039, 710.0 712.0	—	ER4043[e]	ER4043[e,i]	ER5356[i]	ER5356[g]	—	—		—
511.0, 512.0, 513.0, 514.0, 535.0	—	—	ER4043[e,i]	ER5356[i]	—	—	—	—	—
356.0, A356.0, 357.0, A357.0, 413.0, 443.0 A444.0	ER4145	ER4145[e,f]	ER4043[e,k]	—	—	—	—	—	—
319.0, 333.0, 354.0, 355.0, C355.0	ER4145[h]	ER4145[e,f,k]	—	—	—	—	—	—	—
201.0, 206.0, 224.0	ER2319[d,k]	—	—	—	—	—	—	—	—

a. Service conditions may limit the choice of filler metals. Filler metals ER5183, ER5356, ER5556, and ER5654 are not recommended for sustained elevated-temperature service.
b. For gas shielded arc welding processes only. For OAW ER1188, ER1100, ER4043, ER4047, and ER4145 filler metals are used.
c. Where no filler metal is listed, the base metal combination is not recommended for welding.
d. ER4145 may be used for some applications.
e. ER5183, ER5356, ER5554, ER5556, and ER5654 may be used. They may provide improved color match after anodizing treatment, highest weld ductility, and higher weld strength. ER5554 is suitable for sustained elevated-temperature service.
f. ER4043 may be used for some applications.
g. ER5183, ER5356, or ER5556 may be used.
h. ER2319 may be used for some applications to supply high strength when the weldment is postweld solution heat-treated and aged.
i. ER4047 may be used for some applications.
j. ER4643 provides high strength in ½" and thicker groove welds in 6XXX alloys when postweld solution heat-treated and aged.
k. Filler metal of the same composition as the base metal may be used.

Figure 42-5. . .

Base Metal	...FILLER METALS FOR WELDING ALUMINUM ALLOYS — Filler Metal Types[a,b,c]									
	5154, 5254	5086	5083	5052, 5652	5005, 5050	3004, Alc. 3004	2219	2014, 2036	1100, 3003, Alc. 3003	1060, 1070, 1080, 1350
1060, 1070, 1080, 1350	ER5356[e,f,g]	ER5356[g]	ER5356[g]	ER4043[e,g]	ER1100[e,f]	ER4043[e,g]	ER4145[e,f]	ER4145	ER1100[e,f]	ER1188[e,f,k]
1100, 3003, Alc. 3003	ER5356[e,f,g]	ER5356[g]	ER5356[g]	ER4043[e,g]	ER1100[e,f]	ER4043[e,g]	ER4145[e,f]	ER4145	ER1100[e,f]	—
2014, 2036	—	—	—	—	ER4145	ER4145	ER4145[h]	ER4145[h]	—	—
2219	ER4043[e]	—	—	ER4043[e,g]	ER4043[d,e]	ER4043[d,e]	ER2319[d]	—	—	—
3004, Alc. 3004	ER5356[j]	ER5356[g]	ER5356[g]	ER5356[e,f,j]	ER5356[f,j]	ER5356[f,j]	—	—	—	—
5005, 5050	ER5356[j]	ER5356[g]	ER5356[g]	ER5356[e,f,g]	ER5356[f,j]	—	—	—	—	—
5052, 5652	ER5356[j]	ER5356[g]	ER5356[g]	ER5654[f,j]	—	—	—	—	—	—
5083	ER5356[g]	ER5356[g]	ER5183[g]	—	—	—	—	—	—	—
5086	ER5356[g]	ER5356[g]	—	—	—	—	—	—	—	—
5154, 5254	ER5654[j]	—	—	—	—	—	—	—	—	—

. . . **Figure 42-5.** *Filler metals for welding aluminum alloys are selected for the type of base metal to be welded.*

WELDABILITY OF MAGNESIUM ALLOYS

Magnesium is one of the lightest commercial metals. Magnesium is alloyed with many chemical elements to create products with a high strength-to-weight ratio. Some magnesium alloys have strength-to-weight ratios comparable to some aluminum alloys and high-strength steels, making them suitable for high-strength applications where low weight is advantageous. Some wrought magnesium alloys are strengthened by cold working or precipitation hardening, and some cast magnesium alloys are strengthened by precipitation hardening.

Magnesium alloys are grouped broadly according to their cost. The lower cost group of magnesium alloys contain from 2% to 10% aluminum, plus minor amounts of manganese, silicon, and zinc. The second group contains manganese, zinc, rare earth elements, and thorium, plus small amounts of zirconium to refine the grain size. The second group has better properties at higher temperatures, is more difficult to produce, and is much more expensive.

Magnesium alloys are identified by a four-part numbering system indicating chemical composition and temper designation. See Figure 42-6.

The temper designation of magnesium alloys is included in the alloy designation and is similar to the codes used to describe aluminum alloys. For example, T6 describes a temper which is solution treated and artificially aged (precipitation hardened).

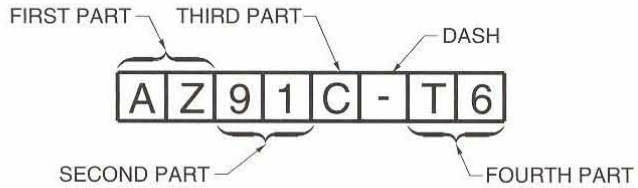
Care must be taken when preparing or repairing magnesium. Magnesium can heat to a combustion point and will ignite.

The best weldability is achieved with magnesium alloys that contain aluminum and zinc, rare earth elements, or thorium.

General Welding Considerations for Magnesium Alloys

The best weldability is achieved with magnesium alloys that contain aluminum and zinc, rare earth elements, or thorium. These alloys are represented by the AM, AZ, ZE, EZ, HK, HM, and HZ series. Alloys with zinc as the major alloying element are more difficult to weld. These alloys are represented by the ZE, ZH, and ZK series.

ASTM MAGNESIUM ALLOY AND TEMPER DESIGNATION



First Part	Second Part	Third Part	Fourth Part
Indicates the two principal alloying elements	Indicates the amounts of the two principal alloying elements	Distinguishes between different alloys with the same percentages of the two principal alloying elements	Indicates temper condition
A-Aluminum E-Rare Earth Elements H-Thorium K-Zirconium M-Manganese Q-Silver S-Silicon T-Tin Z-Zinc	Whole numbers	Letters of alphabet except I and O	F-As-fabricated O-Annealed H10 and H11-Slightly strain hardened H23, H24, and H26-Strain hardened and partially annealed T4-Solution heat-treated T5-Precipitation hardened only T6-Solution heat-treated and precipitation hardened T8-Solution heat-treated, cold worked, and precipitation hardened
Two main alloying elements in order of decreasing percentage or alphabetically if percentages are equal	Percentages of the two main alloying elements and arranged in same order as alloy designations in first part	Letter of the alphabet assigned in order as compositions become standard	Letter followed by a number

Figure 42-6. *The designations for magnesium alloys consist of a four-part numbering system.*

Weldability factors that must be considered before welding magnesium include surface preparation, heat requirements, welding processes, and filler metals.

Surface Preparation. Surface preparation is required to remove the oxide film before welding magnesium. The surface film thickens as the temperature increases, becoming a hindrance to welding. The surface must be thoroughly degreased to remove surface preservatives and then chemically or mechanically cleaned to remove the oxide film. Various chemical cleaning solutions can be used. For critical work, chemical cleaning is followed by mechanical cleaning with a clean stainless steel wire brush, using light pressure to prevent gouging.

Heat Requirements. Heat requirements for welding magnesium alloys are dictated by their high thermal conductivity and high coefficient of thermal expansion. Because of these factors, thick workpieces and highly restrained joints generally require preheat to prevent weld cracking.

Welding Processes. GTAW and GMAW are commonly used for welding magnesium. GTAW is generally used for thin sections and GMAW for medium to thick sections. Argon is the most common shielding gas, but argon-helium mixtures are also used. Most wrought alloys can be readily resistance spot welded. In resistance spot welding, the metal is molten for a very short time and the cooling rate is very high, so there is little time for harmful metallurgical changes to occur.

Filler Metals. Filler metals with a lower melting point and a larger freezing range than the base metal provide good weldability and minimize weld cracking in magnesium alloys. See Figure 42-7.

WELDABILITY OF TITANIUM ALLOYS

Titanium alloys vary from low-strength to high-strength, depending on their metallurgical structure. High-strength titanium alloys have a high strength-to-weight ratio. Strict attention to cleanliness and gas atmosphere is required when welding titanium.

Titanium alloys are grouped into alpha, alpha-beta, and beta alloys according to their metallurgical structure. Alpha alloys are generally the lowest strength. Alpha-beta alloys have higher strength than alpha alloys and are annealed or precipitation hardened. Beta alloys develop extremely high strengths through cold working or precipitation hardening.

Alpha titanium alloys consist of three groups: commercially pure titanium, alpha alloys, and near-alpha alloys. Commercially pure titanium contains very small amounts of interstitial elements. An *interstitial element*

FILLER METALS FOR WELDING MAGNESIUM ALLOYS*

Magnesium Alloy	Filler Metal Types				
	Base Metal	ERAZ61A	ERAZ92A	EREZ33A	ERAZ101A
WROUGHT MAGNESIUM ALLOYS					
AZ10A		X	X		
AZ31B		X	X		
AZ61A		X	X		
AZ80A		X	X		
ZK21A		X	X		
HK31A				X	
HM21A				X	
HM31A				X	
M1A	X				
CAST MAGNESIUM ALLOYS					
AM100A	X		X		X
AZ63A	X		X		X
AZ81A	X		X		X
AZ91A	X		X		X
AZ92A	X		X		X
EK41A	X			X	
EZ33A	X			X	
HK31A	X			X	
HZ32A	X			X	
K1A	X			X	
QH21A	X			X	
ZE41A	X			X	
ZH62A	X			X	
ZK51A	X			X	
ZK61A	X			X	

* ANSI/AWSA 5.19, *Specification for Magnesium Alloy Welding Electrodes and Rods*

Figure 42-7. *Filler metals with a lower melting point and larger freezing range than the base metal provide good weldability for magnesium alloys.*

Stainless steel wire brushes should be used to remove residues from titanium alloys.

is a chemical element added in small amounts, whose atomic size is significantly less than the major elements present in the metal. The primary difference between the various grades of commercially pure titanium is the interstitial element content. Alloys with higher purity (grades 1 and 2) have lower strength and lower hardness than alloys of lower purity (grades 3 and 4). Alpha and near-alpha alloys have improved strength over commercially pure titanium and have high-temperature strength. See Figure 42-8.

Alpha-beta titanium alloys can be strengthened by solution treatment and precipitation hardening to achieve high strengths. Beta titanium alloys are heat-treated to high strength levels by solution treatment and precipitation hardening. Beta alloys also have exceptional work hardening characteristics.

General Welding Considerations for Titanium Alloys

General weldability considerations for titanium alloys are cleaning and shielding, welding processes, and brazing. Cleanliness is the single most important requirement for welding titanium alloys, including effective inert gas shielding to ensure that no atmospheric contaminants enter the material during welding and during cooling from the welding temperature. When using a coated electrode to weld titanium, welding can be performed in a normal atmosphere.

GMAW is commonly used for welding aluminum because welding can be performed rapidly, keeping heat input low.

Titanium Alloy Families
Figure 42-8

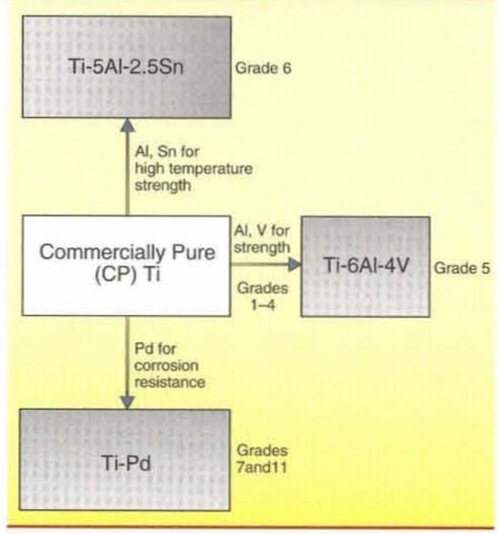


Figure 42-8. *Titanium alloys provide a combination of light weight and relatively high strength.*

Titanium is the fourth most abundant metal, but the difficulty in extracting it results in increased cost.

Cleaning and Shielding Requirements. Cleaning and shielding requirements before and during welding are of paramount importance when welding titanium alloys. Contamination by impurities such as oxygen or nitrogen must be carefully controlled to prevent brittle welds. Oil, fingerprints, grease, paint, and other foreign matter should be removed using a suitable solvent cleaning method. Chloride-containing solvents leave residues that can cause cracking. Hydrocarbon residues can result in oil contamination and embrittlement. Only stainless steel wire brushes should be used to remove residues.

Welding Processes. Welding processes used to weld titanium alloys are GTAW, GMAW, electron beam welding, laser beam welding, or resistance welding. Preheat is not required for titanium alloys.

Welding must be performed with an inert shielding gas such as argon to prevent oxygen and nitrogen pickup. The argon shield must be maintained

on all metal surfaces above a temperature of 1000°F (538°C). The shielding gas used must be free of harmful contaminants and must completely envelop both sides of the metal, both during welding and as the weld cools. The metal as it cools from welding temperature must also be protected by a trailing shield. See Figure 42-9.

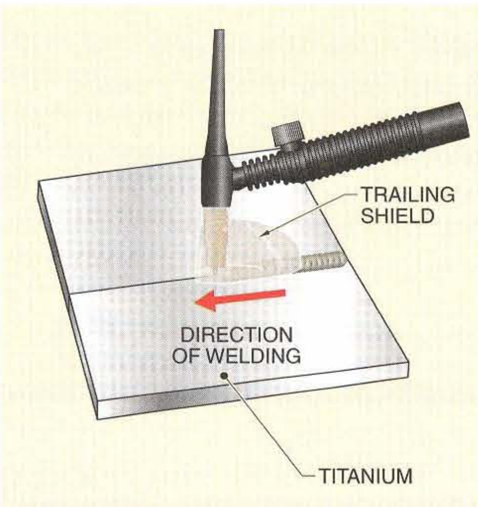


Figure 42-9. *The metal cooling from welding temperature must also be protected by a trailing shield.*

Brazing. Brazing may be performed on titanium alloys. Brazing has very little effect on the properties of alpha alloys. The mechanical properties of alpha-beta alloys can be severely reduced by brazing. The brazing temperature must be below 1650°F (899°C) to prevent reduction in mechanical properties. Beta alloys are unaffected when used in the annealed condition.

Specific Welding Considerations for Titanium Alloys

Most titanium alloys do not require heat treatment after welding to restore mechanical properties. Specific welding considerations depend on the alloy group.

When burning titanium, wear a dark lens helmet to protect from the brightness of the material.

Alpha Titanium Alloys. Alpha titanium alloys have good weldability because they are ductile. Welding or brazing operations have little effect on the mechanical properties of annealed material. Commercially pure titanium is usually welded with a filler metal one grade below that of the base metal because welding operations lead to slight pickup of oxygen and nitrogen. For example, grade 2 titanium (.25% O) is welded with grade 1 titanium filler metal (.18% O).

Alpha-Beta Titanium Alloys. Alpha-beta titanium alloys may undergo harmful strength, ductility, and toughness changes when welded. Ti-6Al-4V has the best weldability of the alpha-beta alloys and can be welded in either the annealed condition or the partially precipitation hardened condition. Precipitation hardening may be completed during postweld stress-relief heat treatment. Alpha-beta titanium alloys may suffer significant mechanical property loss during welding. Alpha-beta titanium alloys may be welded with commercially pure titanium filler metals to increase joint ductility.

Beta Titanium Alloys. Beta titanium alloys are weldable in either the annealed or the heat-treated condition. Weld joints have good ductility but relatively low strengths as welded. Beta titanium alloys are welded with matching filler metals. They are not usually heat-treated after welding, because even though filler metals match the base metals in chemical composition, their response to heat treatment is different.

POINTS TO REMEMBER

1. Nickel alloys are extremely sensitive to cracking from contamination, and the joint must be thoroughly cleaned before welding.
2. Remove the oxide film from the surface to be welded and use heavily coated filler metals specially designed for Monel® and Inconel®.
3. Commercially pure coppers are wrought or cast and are used primarily for their high electrical conductivity.
4. Use heavily coated phosphor-bronze filler metals when welding tin bronze and make small deposits of beads at a time.
5. The surface film must be removed from aluminum alloys before fusion or resistance welding, and must be prevented from re-forming by means of an inert gas shield or by pressure between the joint surfaces.
6. The best weldability is achieved with magnesium alloys that contain aluminum and zinc, rare earth elements, or thorium.
7. Stainless steel wire brushes should be used to remove residues from titanium alloys.

QUESTIONS FOR STUDY AND DISCUSSION

1. What is the copper content of commercially pure coppers?
2. Brass is an alloy consisting of what elements?
3. What are the principal alloying ingredients in bronze?
4. What is fluidity?
5. What are some of the outstanding properties of aluminum?
6. Why should the surface film be removed before welding on aluminum?
7. Which alloying elements provide the best weldability when added to magnesium?
8. Why must titanium alloys be absolutely clean before and during welding?
9. Why does distortion occur in nickel alloys?
10. What must be done to the surface of Monel® and Inconel® before welding?
11. When welding Monel® or Inconel®, what type of current should be used?

Distortion Control 43

Welding Technology

Distortion is the undesirable dimensional change of a fabrication. Distortion occurs because of nonuniform expansion and contraction of weld metal and adjacent base metal from the welding process. Distortion makes it difficult to maintain proper fit-up as welding progresses. Expensive remedial work may be required to correct a job after completion. Distortion from welding also contributes to residual stresses. Distortion is controlled by the welding procedure, and by restraints and heat shaping used to accommodate shrinkage. Fabrication codes and standards have requirements for maximum allowable distortion.

DISTORTION

Distortion is the undesirable dimensional change of a fabrication. Distortion is related to the direction of the weld and varies with the weld joint configuration. Distortion in welding arises from weld metal shrinkage and base metal shrinkage that accompany cooling. Distortion and shrinkage lead to high residual stresses in the metal. The part may be forced out of alignment as residual stresses in the weld joint ease and cause the part to move.

Weld Metal Shrinkage

Weld metal shrinkage occurs as metal cools, producing distortion in a weld. As a weld begins to solidify, it is expanded to its maximum. As the metal cools and solidifies, it attempts to contract in volume, but adjacent base metal prevents (restrains) it from doing so.

The restraint causes stresses within the weld to increase and finally exceed the yield strength of the metal. Once the yield strength is exceeded, the weld metal begins to stretch, thinning out and adjusting to the new volume requirements. Only those stresses that exceed the yield strength are relieved by this accommodation. By the time the weld reaches ambient temperature—assuming it is completely restrained by the base metal and cannot move—the weld contains locked-in tensile stresses approximately equal to its yield strength.

Shrinkage in weld metal may be transverse or longitudinal. *Transverse shrinkage* is shrinkage that occurs perpendicular to the weld axis. Transverse shrinkage depends on the volume of weld metal, plus the amount of the root opening. Some shrinkage will occur whether or not the joint is made with a root opening. *Longitudinal shrinkage* is shrinkage that occurs parallel to the weld axis. See Figure 43-1.

Groove Welds. Several weld passes are often necessary to complete a groove weld. The root pass creates little or no distortion, but restrains the two components being joined. As the second pass solidifies, it shrinks, but the solidified root pass offers restraint (no movement), so that the shrinkage must

Distortion in welding is caused by shrinkage in the weld metal and the base metal that occurs during cooling.

Distortion of welded structures is either transverse (at 90° to the weld axis) or longitudinal (along the length of the weld axis).

occur within the second pass and toward its upper surface. Successive passes are larger and wider and there is a greater mass of weld metal shrinking. For groove welds in carbon steel with a 60° groove angle, the transverse shrinkage rate is typically 1/16″ to 1/8″ per weld pass.

Weld Metal Shrinkage
Figure 43-1

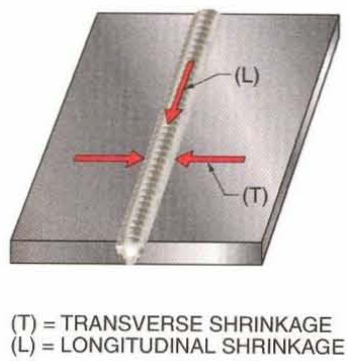


Figure 43-1. *Distortion is caused by weld shrinkage, which can be transverse (T) or longitudinal (L).*

Each new pass goes through a solidifying shrinkage cycle as it cools, with the previous pass acting as restraint. The weld works like a hinge: the weld root is the hinge pin, and the faces of the joint (the flat parts of the hinge) are drawn to one another with the shrinkage of each pass. The result is transverse shrinkage.

In a groove weld, the joint is also strained in tension in the longitudinal direction. The resulting distortion is observed as longitudinal contraction of the weld. Longitudinal shrinkage is less of a problem in groove welds than transverse shrinkage. See Figure 43-2.

Distortion in weld parts can be controlled by setting parts out of position so that the effects of welding pull the parts into alignment, or by welding parts in their correct position and then using heat-shaping methods to straighten the parts. Restraints may be used to hold parts in position; however, restraint introduces residual stresses into the parts, which also must be controlled.

Distortion in Groove Welds
Figure 43-2

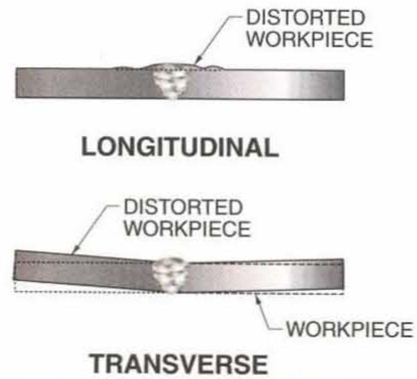


Figure 43-2. *Residual stresses in groove welds cause transverse and longitudinal distortion.*

Fillet Welds. Distortion in fillet welds is more complex than in groove welds. It results partially from the location of the center of gravity of the workpieces in relation to the fillet weld. A single fillet weld creates transverse shrinkage. For fillet welds in carbon steel, the transverse shrinkage rate is 1/32″ per weld pass (where the leg length of the weld does not exceed three-quarters of the base metal thickness). When the root pass is laid, the workpieces being joined become integral with one another. As more passes are laid, there is more shrinkage at the face of the fillet than at the root, because the face receives a greater amount of filler metal. To accommodate the weld metal shrinkage, the workpieces being joined move toward one another, creating transverse shrinkage. The greater the number of weld passes, the greater the distortion. See Figure 43-3.

A double fillet weld, if properly made, does not exhibit transverse shrinkage. However, it is still susceptible to longitudinal shrinkage. If the fillet weld of the T-joint is above the center of gravity of a welded structure, the metal distorts longitudinally upward at its ends. If the fillet weld is below the center of gravity, it distorts longitudinally downward at its ends. See Figure 43-4.

Distortion in Fillet Welds
Figure 43-3

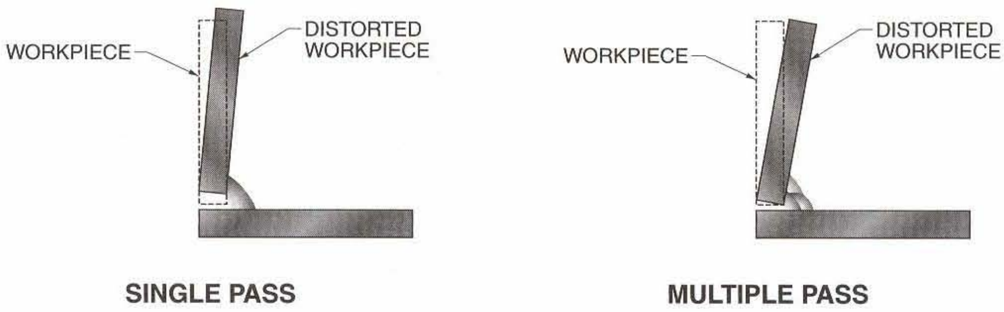


Figure 43-3. *When weld beads are deposited in a single fillet weld, shrinkage occurs at the face of the fillet because of the amount of filler metal deposited.*

Distortion in Double Fillet Welds
Figure 43-4

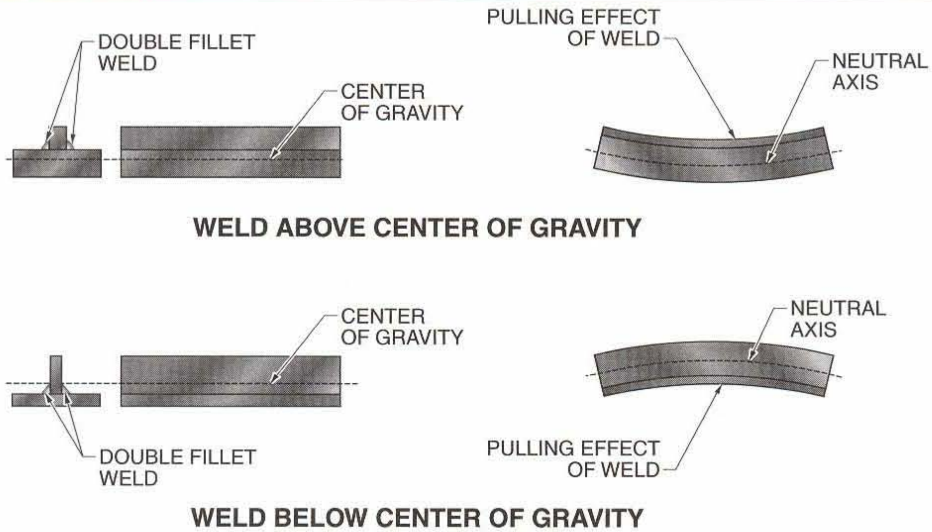


Figure 43-4. *In a double fillet weld, longitudinal distortion is determined by the location of the center of gravity.*

Base Metal Shrinkage

During welding, the HAZ is heated close to its melting point. Less than an inch away, the base metal temperature is substantially lower because it is less affected by the heat of welding. The intense temperature difference causes expansion of the HAZ, followed by base metal movement. As the welding arc moves along the joint, the source of heat is relocated and the formerly heated part of the base metal (the HAZ) begins to cool and shrink. If the unaffected base metal restrains it from contracting, stresses in the HAZ build up. These stresses, combined with stresses that develop in the weld metal as it cools, increase distortion in the base metal.

DISTORTION CONTROL

Distortion may cause poor fit-up during fabrication and lead to undesirable stresses. Distortion control is necessary to overcome poor fit-up and undesirable stresses, and to meet specific dimensional requirements. Fabrication codes and standards have requirements for maximum allowable distortion. Distortion control includes methods to minimize or eliminate distortion to

Modifying the welding procedure, using special welding techniques,using mechanical restraints, and heat shaping can help control distortion.

Proper fit-up is essential on thin metals. Closely spaced tack welds must be used to control distortion.

meet code requirements. Modifying the welding procedure, using special welding techniques, using mechanical restraints, and heat shaping are methods that can help control distortion.

Welding Procedures

The welding procedure may be modified to minimize or control distortion. Welding procedures that may be modified to prevent distortion include fit-up and edge preparation; preheat; welding process and travel speed; weld metal deposited; and weld passes.

Fit-up and Edge Preparation. Proper fit-up and edge preparation help ensure that the correct amount of weld metal is used in a joint. If gaps occur in a joint, the welder must slow down to fill them, using more filler metal than specified and increasing contraction across the joint. Ensure that the joint has the proper fit-up and that the correct edge preparation is used to eliminate the need for excessive filler metal and increased joint contraction. Undercut spots in butt joints can be filled by weld buildup on the edge of the base metal before welding to improve poor fit-up. Joint preparation cannot be manipulated for fillet welds as it can for groove welds.

For a butt joint, a minimum root opening of ⅛″ is desired. A 60° groove angle allows for complete penetration at the root yet requires minimal weld metal. For thick metal, increasing the root opening to $\frac{3}{16}$″ allows the groove angle to be decreased. Alternatively, a J-groove may be used to reduce the amount of weld metal required. A double-V-groove may be used, which reduces by half the amount of weld metal necessary compared with a single-V. See Figure 43-5.

If the root opening is increased and the groove angle is reduced, the amount of metal deposited at the root and at the face of the weld is more equal, reducing transverse shrinkage.

A square groove on thin metals reduces distortion but does not completely eliminate it.

On sheet metal, tack welds are light. On very thin metal, small, closely spaced tack welds are the only means of controlling distortion. After tack welding, the entire joint should be lightly hammered before welding. On very thin material (26-gauge and thinner), almost continuous tack welds may be required.

Butt Joint Fit-up and Edge Preparation
Figure 43-5

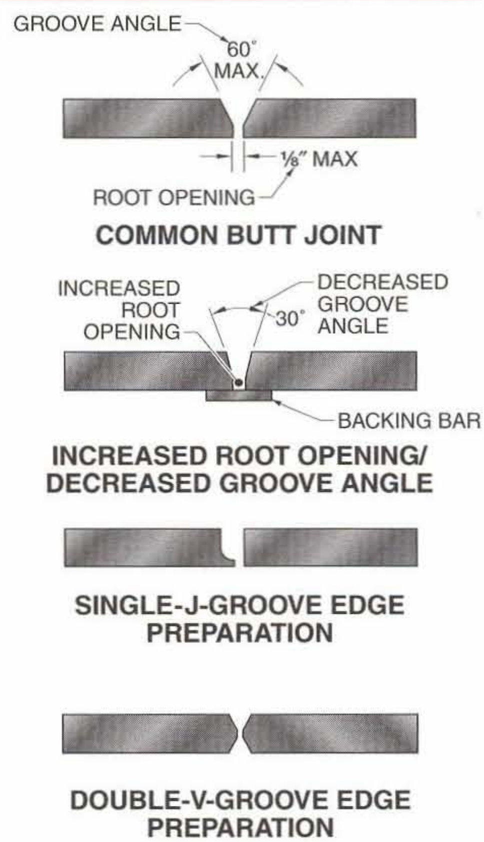


Figure 40-5. *Butt joint fit-up and edge preparation can be altered to help control distortion.*

Preheat. Properly applied preheat can help reduce weld distortion and residual stresses because it lowers the temperature gradients in the metal around the weld. On steel, preheat also reduces the tendency for cracking in the HAZ or the weld metal.

Welding Process and Travel Speed. The welding process used can influence distortion. Automatic and semiautomatic welding processes use higher travel speeds and greater deposition rates per pass than manual welding processes, resulting in less distortion. Additionally, with automatic welding processes, progressive shrinkage of the weld as it cools (which occurs in manual welding during the interval between each weld pass) is eliminated.

When using manual welding processes, GMAW produces less distortion than GTAW, and PAW produces less distortion than GMAW. In addition, with PAW, thicker metals can be welded than can be welded with GTAW or GMAW. Oxyfuel welding processes produce more distortion than arc welding processes because heating of the base metal is slow and more heat is required to offset the heat loss from diffusion.

Weld metal should be deposited in the shortest possible time to minimize heat input. Increasing the travel speed reduces the amount of base metal affected by the welding heat and reduces distortion.

Weld Metal Deposited. The greater the amount of weld metal deposited in a joint, the greater the chance of shrinkage. To minimize shrinkage, only the required amount of weld metal should be used.

The effective throat in a fillet weld determines the weld joint strength. A fillet weld that yields an effective throat size that is just sufficient for the strength required by the weld design is preferred. In a butt joint, excess weld metal in a highly convex bead does not increase the allowable strength of the weld in the design code, but does increase shrinkage and distortion. See Figure 43-6.

Weld Passes. Shrinkage in a weld is cumulative. The more weld passes made, the more shrinkage occurs. A few passes made with a large-diameter filler metal are preferable to many passes made with a small-diameter filler metal. Making fewer passes also reduces welding time, which reduces the amount of heat at the weld so less expansion of the metal surrounding the weld occurs.

Excess Weld Metal
Figure 43-6

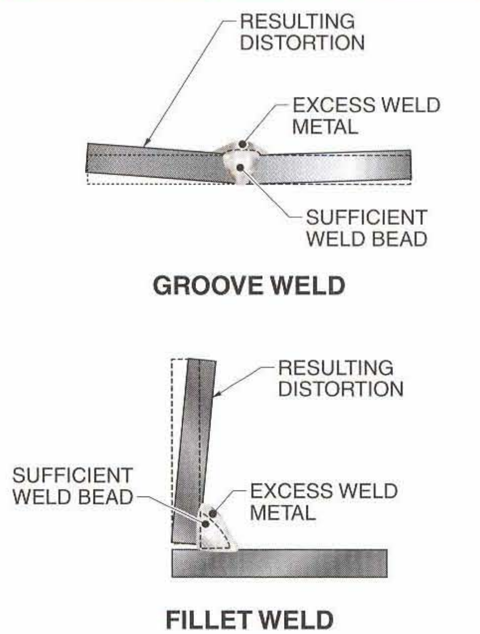


Figure 43-6. *Excess weld metal increases distortion in a weld.*

Welding Techniques

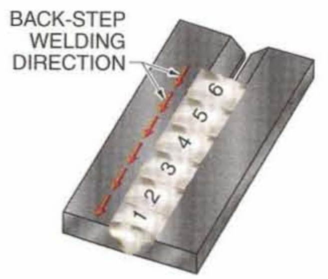
Various welding techniques may be used to balance shrinkage stresses and control distortion. Typical welding techniques used include back-step welding and intermittent welding.

Back-Step Welding. *Back-step welding* is a welding process in which weld passes are made in the direction opposite to the progress of welding. Each weld pass locks the workpieces being joined. The greatest amount of metal expansion occurs when the first weld bead is deposited. Metal expands less with each successive weld bead because of the locking effect of previous back-step welds. See Figure 43-7. Back-step welding cannot be performed with automatic welding processes.

The greatest amount of metal expansion occurs when the first weld bead is deposited. Metal expands less with each successive weld bead because of the locking effect of previous back-step welds.

Figure 43-7. *Back-step welding is a welding process in which weld passes are made in the direction opposite to the progression of welding.*

Back-Step Welding
Figure 43-7

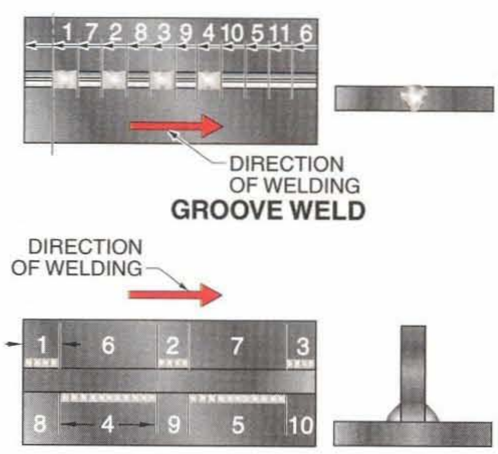


> *Mechanical restraints cause a buildup of internal stresses in the weld to the point that the yield stress of the weld is exceeded.*

Intermittent Welding. Intermittent welding is an alternative to back-step welding. Intermittent welding is performed by depositing weld metal in evenly spaced increments. On a T-joint, welds are alternated on either side of the joint. Three short (usually 1″) weld beads are made, and then two longer beads (3x the length of the short beads) are made on the other side of the T-joint. The direction of welding should remain the same throughout the process, but it is not necessary for the direction to be opposite to the general progression, as with back-step welding. See Figure 43-8.

Figure 43-8. *In intermittent welding, weld metal is deposited in evenly spaced increments.*

Intermittent Welding
Figure 43-8



Intermittent welding may be used to reduce the amount of weld metal required and must be allowed by the design code. Intermittent welding is not used where corrosion is an issue because intermittent fillet welds create crevices that may allow corrosives to enter the weld area.

Mechanical Restraint Methods

A *mechanical restraint* is a device used to restrict movement and counteract shrinkage stresses that occur during welding. The restraint holds the part in the desired position until welding is completed. The restraint causes a buildup of internal stresses in the weld until the yield stress of the weld is exceeded. The part is restrained until it cools and the internal stresses are eased. Once the part has cooled, the restraint is removed, with little distortion or movement. Movement does not occur when the restraint is removed because cooled, solid metal is under less strain than hot, restrained metal. Typical mechanical restraint methods are strongbacks, back-to-back positioning, and prebending.

Strongbacks. A *strongback* is a mechanical restraint device that is attached to one side of a weld joint to hold workpieces in alignment during welding. For example, cylindrical shell plates that have been over-rolled have seams that are peaked (pointed inward) before welding is started. The strongback prevents angular misalignment during welding and prevents further peaking as a result of welding, while leaving the joint free to shrink transversely.

Strongbacks may be used to pull the bent structure into alignment. Flame heating can then be systematically applied to the restrained member. A straightedge, scale, or dial indicator may be used to determine the movement achieved. The part must remain in the desired shape after it has cooled and the external restraint has been removed. The mechanical restraint is only removed after the part has cooled to room temperature.

Back-to-Back Positioning. *Back-to-back positioning* is a mechanical restraint method that places identical weldments back-to-back and clamps them together. The welds are completed and both weldments are allowed to cool before the clamps are released. The weldments counteract each other and cancel out distortion. See Figure 43-9.

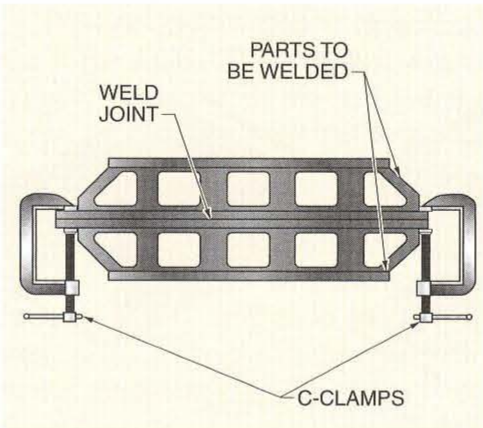


Figure 43-9. *Back-to-back positioning counteracts shrinkage in two identical components.*

Prebending. *Prebending* is a mechanical restraint method that relies on locating workpieces out of position before welding so that welding shrinkage stresses pull the workpieces into position. Prebending may be achieved by modifying the fit-up or using clamps to pre-spring parts before they are welded. The clamps are removed after welding. Residual stresses in the part cause the part to straighten.

Heat Shaping

Heat shaping is the application of localized heating to cause movement of a distorted part and restore its dimensions. Heat shaping is applied using an oxyacetylene flame. Heat shaping requires temperature monitoring and measurement of the movement achieved. In some cases, movement may be assisted with mechanical devices. For complete correction of distortion, mechanical restraints may be used with heat shaping. Four basic heating patterns are used when heat shaping: line-, spot-, V-, and block-heating. See Figure 43-10.

The line-heating pattern can be used on metal plate. The metal is heated on the convex (high) side that is to be bent down. A slightly oscillating torch follows the line, with the oscillations about as wide as the metal thickness. The torch progresses across the metal at a constant speed to bring the plate to temperature. See Figure 40-11. Movement in a line-heating pattern progresses in a linear fashion with relatively little width compared to its length.

The four basic heating patterns used when heat shaping metals are the line-, spot-, V-, and block-heating.

Heat Shaping Methods
Figure 43-10

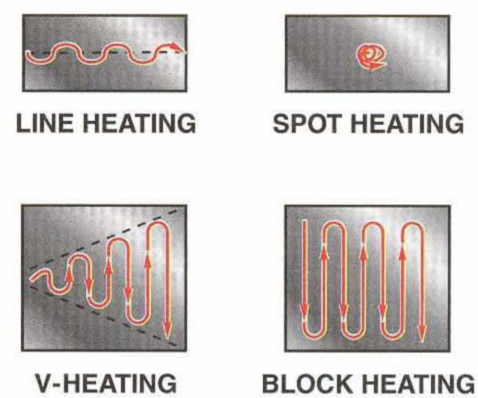


Figure 43-10. *The four basic heat shaping patterns are the line-, spot-, V-, and block-heating methods.*

Line-Heating
Figure 43-11

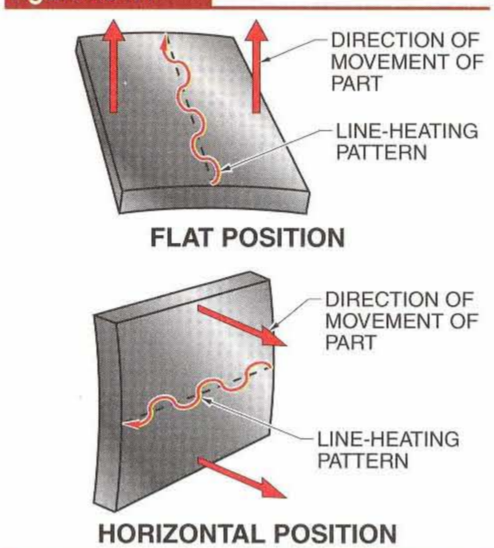


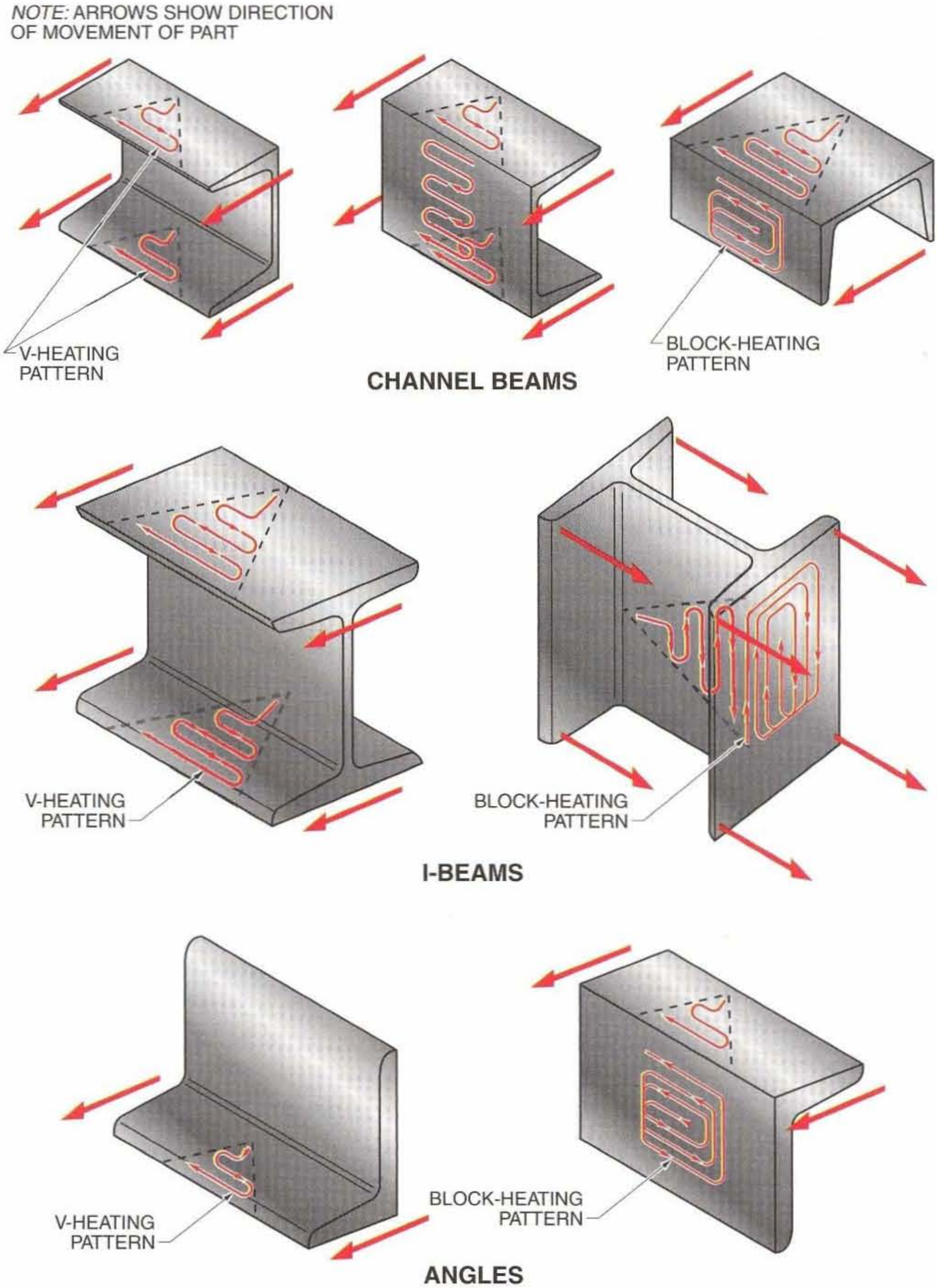
Figure 43-11. *Line-heating is used to bring a distorted piece of metal back into alignment.*

Heat shaping is the application of localized heating to cause movement of a distorted part and restore its dimensions.

The spot-heating pattern concentrates heat in one area in a circular motion and is applied with little, if any, forward motion. The V-heating pattern starts at one point and moves in a linear fashion along a marked axis, weaving back and forth, becoming progressively wider. The block-heating pattern moves in a linear fashion, weaving back and forth to create a rectangular area. The V- and block-heating patterns can be used on structural steel shapes such as channel beams, I-beams, and angles. See Figure 43-12. The patterns are alternately applied to achieve straightening. Two torches may be applied opposite one another in specific cases.

Figure 43-12. *Heat shaping of structural steel sections uses combinations of V- and block-heating patterns to achieve straightening.*

V- and Block-Heating
Figure 43-12



⚠ CAUTION

When a material is being heat shaped, its strength is reduced. If the material is under load, the effects of reduced strength on the material's ability to support loads must be determined; otherwise, catastrophic failure may occur.

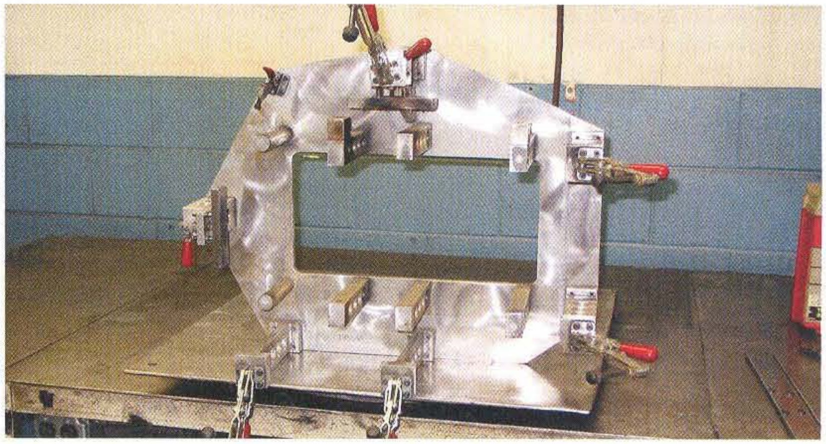
To perform heat shaping, the area to be heat shaped is marked with soapstone, paint stick, or other marking material that is insensitive to heat. When heat shaping stainless steels and nickel alloys, the marking material must contain minimal amounts (less than 250 parts per million) of chlorides, sulfur, or other harmful elements such as zinc; otherwise, cracking may occur during heat application.

The oxyacetylene torch is ignited and the flame adjusted. A localized area is quickly heated, with the point of the flame far enough above the surface to prevent the surface from melting. The torch is weaved slightly, but not advanced in a heating pattern until the starting point reaches the specified temperature. Heat is progressively applied to the marked area, maintaining the desired temperature at the point of the flame. The flame is not backtracked over any area already heated. A temperature-indicating crayon or a contact pyrometer may be used to monitor the temperature.

Distortion Control of Components

Special considerations may be required to prevent distortion in flush patches, piping branch connections, and equipment nozzles.

A *flush patch* is a patch applied to a component that provides a smooth transition between the component and the patch. A flush patch is set much like a window so that there is no ledge or raised surface between the patch and the component. A flush patch is used to repair thin, flat surfaces. When a flush patch is used, the surface may become distorted from shrinkage stresses. Distortion can be minimized using an intermittent welding technique and a slightly dished flush patch. See Figure 43-13. Dishing of the patch allows it to draw in and settle relatively free from stress. The amount of dishing should be about equal to the thickness of the metal being welded.



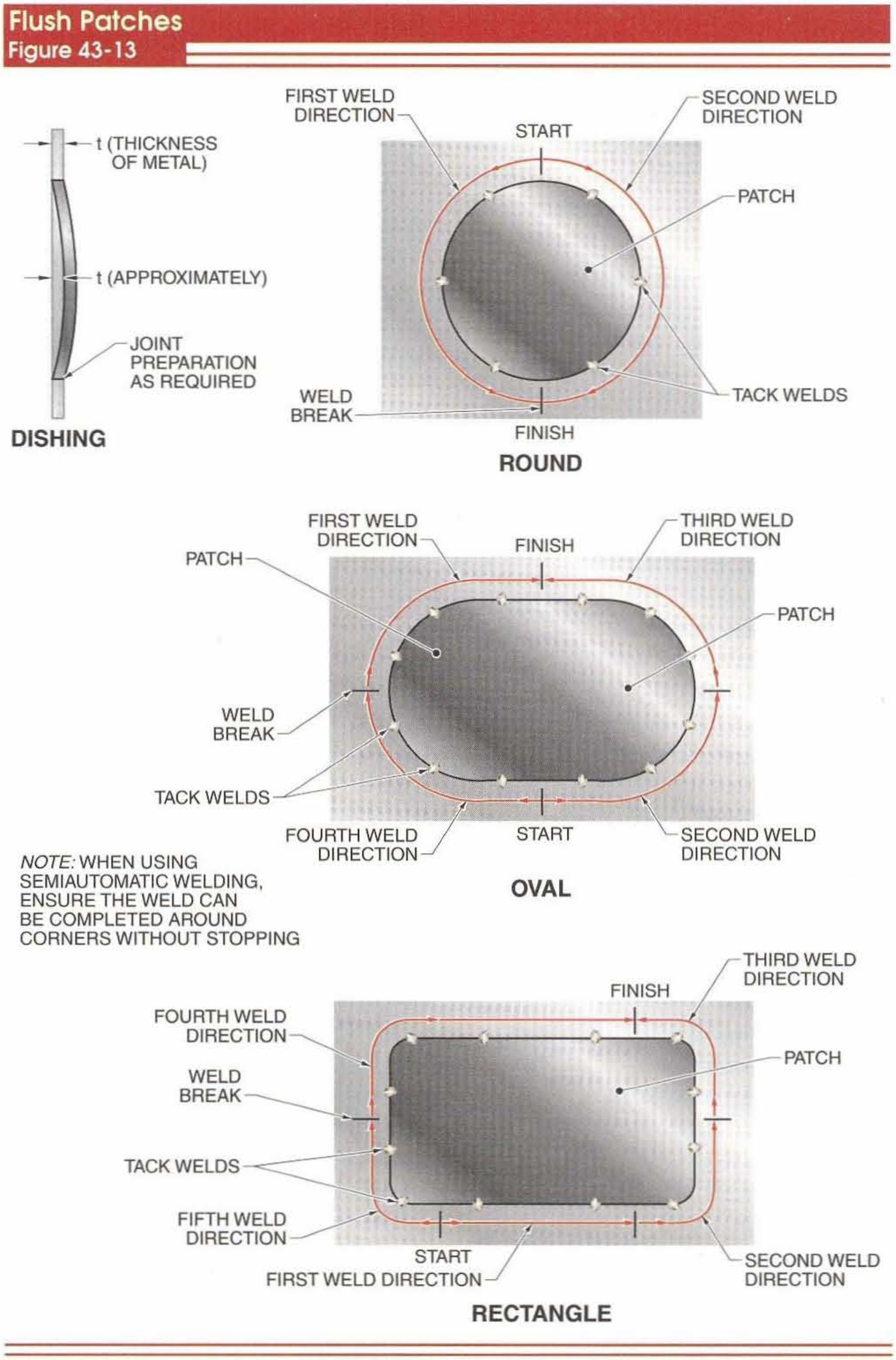
A jig or fixture must be used to restrain parts in position to control distortion during welding.

Distortion may occur when welding pipe branch connections. Distortion can be transverse shrinkage of a groove weld in adjoining pipe sections or unbalanced shrinkage in branch welds. Transverse shrinkage of a groove weld causes a reduction in the overall length of the pipe. In most cases, carbon steel shrinkage is approximately 1/16″, plus or minus 1/32″, per butt joint. Carbon steel shrinkage should be allowed for in the overall length of the piping assembly.

Branch welds can cause piping to bow due to shrinkage on one side. Branch welds must be welded in sequence to minimize distortion of the pipe. The branches furthest from the center of the pipe assembly are welded first because they cause less distortion. If the pipe is bent because of welds at the first two branches, the third branch welding will straighten the pipe. See Figure 43-14.

Distortion may occur during the placement of nozzles on equipment, such as on small-diameter heat exchangers, because the shell thickness is generally less than 3/4″. Distortion increases as the metal cross section (shell thickness) becomes thinner. Distortion on equipment nozzles appears as a flat spot on the shell where the nozzle is welded. Distortion also causes the nozzle to sink into the shell. When welding to thin parts, an internal mechanical restraint, such as a jack, should be used to prevent the shell from collapsing.

Figure 43-13. *Flush patches on thin surfaces may be welded without distortion using an intermittent welding technique and slightly dished flush patch.*



Welders must protect against residual stresses as their presence generally goes unrecognized until failure occurs.

RESIDUAL STRESS

Residual stress is locked-in stress in materials that occurs as a result of manufacturing processes such as casting, welding, forming, or heat treatment. Residual stresses can be detrimental to metals, both alone and under normal service stresses, and can contribute to fatigue and other mechanical failure. Residual stresses can also lead to stress corrosion cracking

of some materials in specific corrosive environments. For example, welded carbon steel equipment and piping operating in hot caustic service must be given stress relief heat treatment to prevent caustic stress cracking at the weld. The presence of residual stresses generally goes unrecognized, so welders must be cautious to protect against them before they occur.

Residual stress and distortion control requirements for many welding applications are detailed in AWS ARE-7, Residual Stress and Distortion. *Other standards and codes may also apply, depending on the locale.*

Branch Welds
Figure 43-14

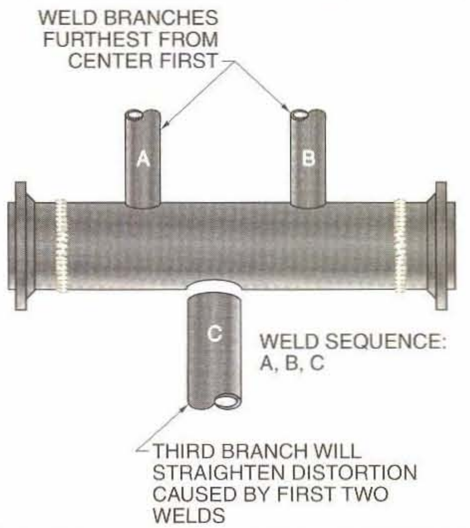


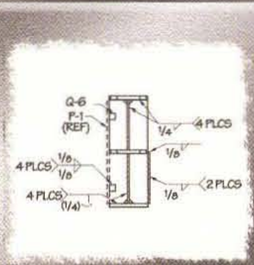
Figure 43-14. *Balanced welding of branch welds reduces the tendency of pipe to distort.*

POINTS TO REMEMBER

1. Distortion in welding is caused by shrinkage in the weld metal and the base metal that occurs during cooling and by creating restraint that exceeds the yield strength of the material.
2. Distortion of welded structures is either transverse (at 90° to the weld axis) or longitudinal (along the length of the weld axis).
3. Modifying the welding procedure, using special welding techniques, using mechanical restraints, or heat shaping can help control distortion.
4. Proper fit-up is essential on thin metals. Closely spaced tack welds must be used to control distortion.
5. The greatest amount of metal expansion occurs when the first weld bead is laid. Metal expands less with each successive weld bead because of the locking effect of previous back-step welds.
6. Mechanical restraints cause a buildup of internal stresses in the weld to the point that the yield stress of the weld is exceeded.
7. The four basic heating patterns used when heat shaping metals are the line-, spot-, V-, and block-heating patterns.
8. Heat shaping is the application of localized heat to a structure to cause beneficial movement of a part to counteract distortion.
9. To completely correct distortion, mechanical restraints may be used with heat shaping.
10. Welders must protect against residual stresses as their presence generally goes unrecognized until failure occurs.

QUESTIONS FOR STUDY AND DISCUSSION

1. How does the heat of welding cause distortion?
2. What happens to molten weld metal as it cools that contributes to distortion?
3. In what two directions does weld metal shrinkage occur?
4. How does preheat help to reduce distortion?
5. Why is it important to use only the minimum thickness of weld filler metal prescribed by the applicable fabrication code?
6. Is distortion more likely to occur in multiple-pass welds or single-pass welds?
7. What is the difference between back-step welding and intermittent welding as distortion prevention methods?
8. Name two methods of mechanical restraint used to prevent distortion.
9. What is heat shaping?



Welding Symbols 44

Welding Technology

When fabricating metal products, a welder may use a print that details product specifications. The print specifies where welds are to be located, the type of joints, and correct weld sizes. Information is indicated by a set of symbols that have been standardized by the American Welding Society (AWS).

WELDING SYMBOLS

A *welding symbol* is a graphical representation of the specifications for producing a welded joint. A welding symbol has instructions attached as to the type of weld required, the location of the weld, whether it is a field weld or a shop weld, and other reference data that are necessary to do a complete welding job. Welding symbols may be very complex and carry a large amount of information, or they may be quite simple. The welding symbol is designed so that specific information has a designated location on the symbol. See Appendix.

A welding symbol is a graphical representation of the specifications for producing a welded joint.

Reference Line

The foundation of the welding symbol is a reference line with an arrow at one end. The arrow points to the location of the weld. Instructions regarding the type of weld are indicated either above or below the reference line. See Figure 44-1. Also included is reference data such as the surface contour of the weld, the size of the weld bead, the length of the weld, how weld beads are to be finished, and often, what type of welding process is to be used. All welding symbol data are indicated with geometric figures, numerical values, and abbreviations.

Designating Types of Welds

The most important factor in a welding symbol is the type of weld. Types of welds are fillet, plug or slot, spot or projection, seam, or groove. Weld types are indicated by a weld symbol. A *weld symbol* is a graphic symbol connected to the reference line of a welding symbol specifying the weld type. Groove welds can be further divided and classified according to the particular shape of the grooved joint. See Figure 44-2. Each weld has its own specific symbol. For example, a fillet weld is designated by a right triangle, and a plug weld by a rectangle. The type of weld used is directly related to the type of joint used: butt, lap, T, or edge.

Instructions regarding the type of weld are indicated either above or below the reference line.

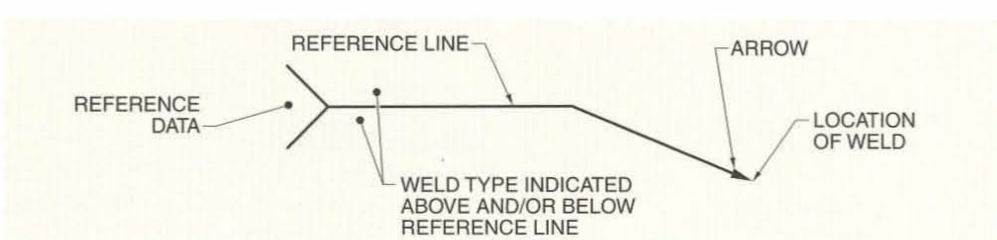
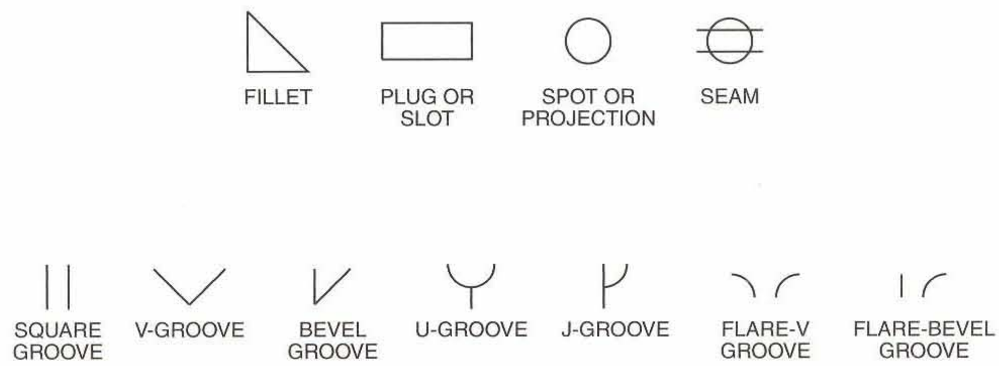


Figure 44-1. *The foundation of the welding symbol is a reference line with an arrow at one end.*

Figure 44-2. *Types of welds are fillet, plug, spot or projection, seam, and groove. Groove welds can be subdivided by the particular shape of the butt joint.*

Weld Types
Figure 44-2

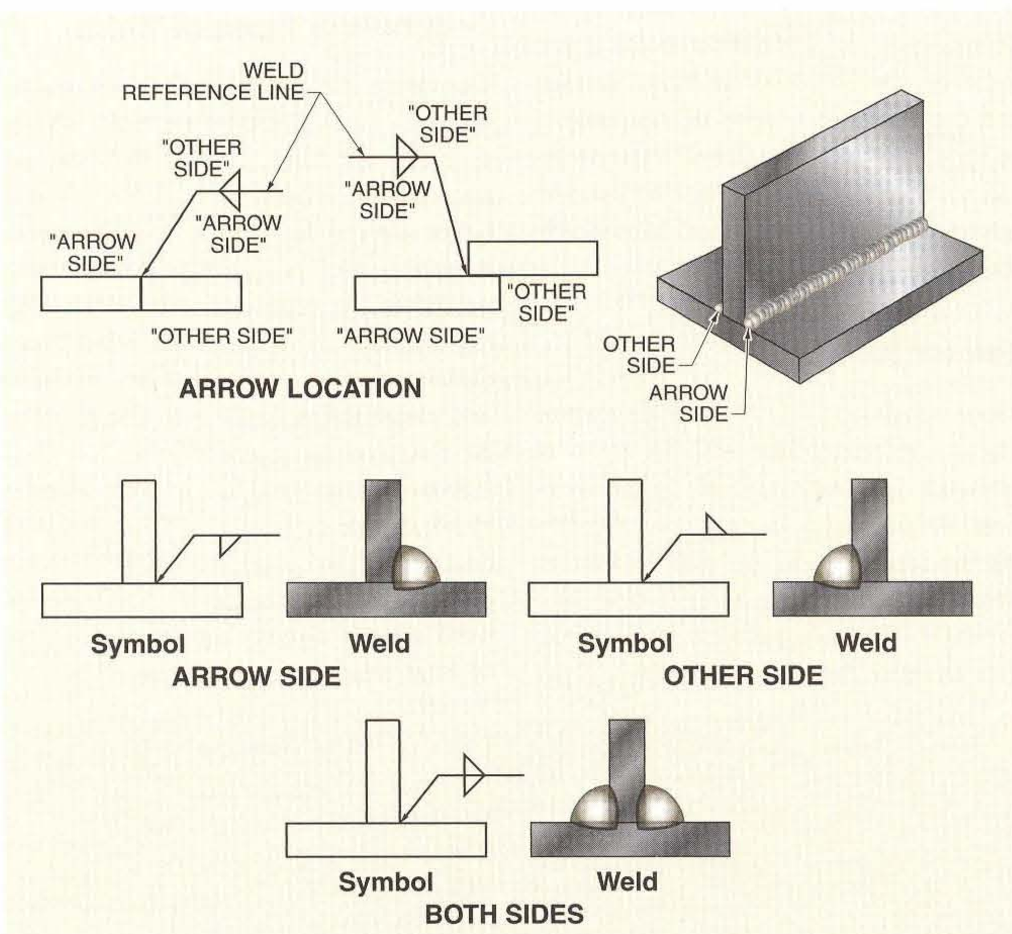


The arrow side is the surface that is in the direct line of vision of the welder. The other side is the opposite surface of the joint.

Symbol Location

The location of the weld symbol on the reference line specifies on which side of a joint a weld is to be made. Weld location is designated by running the arrowhead of the reference line to the joint. The arrow can be directed to either side of a joint and can extend upward or downward. A weld is said to be on either the "arrow side" or the "other side" of a joint. The *arrow side* is the surface that is in the direct line of vision of the welder. The *other side* is the opposite surface of the joint. See Figure 44-3.

Figure 44-3. *Location of the weld symbol on the reference line—on the arrow side or on the other side—determines where the weld is to be made.*



If the weld is to be made on the arrow side, the appropriate weld symbol is placed below the reference line. If the weld is to be located on the other side of the joint, the weld symbol is placed above the reference line. When both sides of the joint are to be welded, the same weld symbol appears above and below the reference line.

A more complete treatment of symbols as they apply to all forms of manual and mechanized welding can be found in AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination,* published by the American Welding Society. See Appendix.

The only exception to the indication of weld location on the reference line is in spot and seam welding. With spot or seam welds, the arrowhead is run to the centerline of the weld seam and the appropriate weld symbol centered above or below the reference line. See Figure 44-4. If no arrow side or other side is important, the symbol is placed astride the reference line to indicate this condition.

On beveled joints, it is often necessary to show which weld part is to be beveled. In such cases, the arrow points with a definite break toward the part to be beveled. See Figure 44-5. Information on welding symbols is placed to read from left to right along the reference line in accordance with the conventions of drafting.

Beveled Joints
Figure 44-5

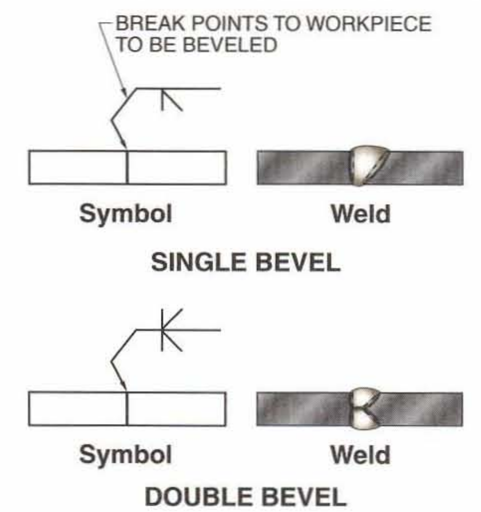


Figure 44-5. *The arrow break points toward the joint that must be beveled.*

Fillet, bevel, J-groove, and flare-bevel groove weld symbols are shown with the perpendicular leg always to the left of the weld symbol. See Figure 44-6.

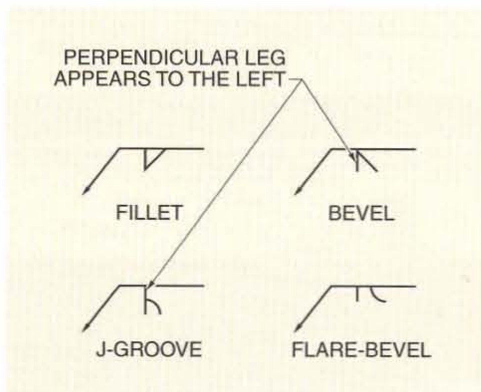


Figure 44-6. *For fillet, bevel, J-groove, and flare-bevel groove joints, the perpendicular leg always appears to the left of the weld symbol.*

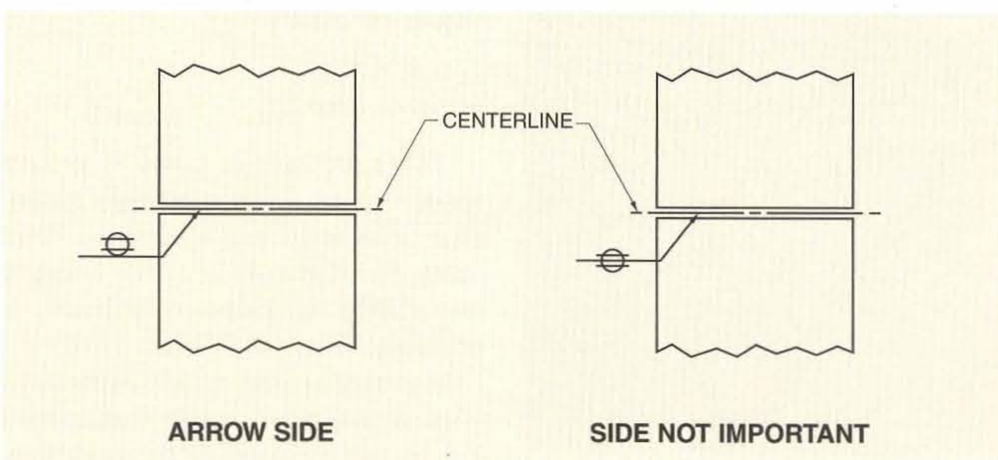


Figure 44-4. *For a seam weld symbol, the arrow is run to the centerline of the weld seam, with the appropriate symbol above or below the reference line. If side is not important, the symbol is placed astride the reference line.*

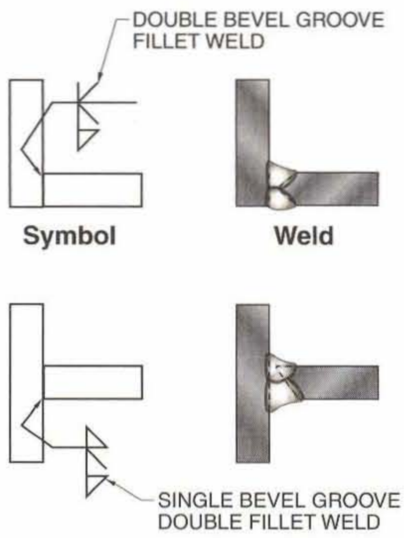
When more than one type of weld is required, a symbol is shown for each weld.

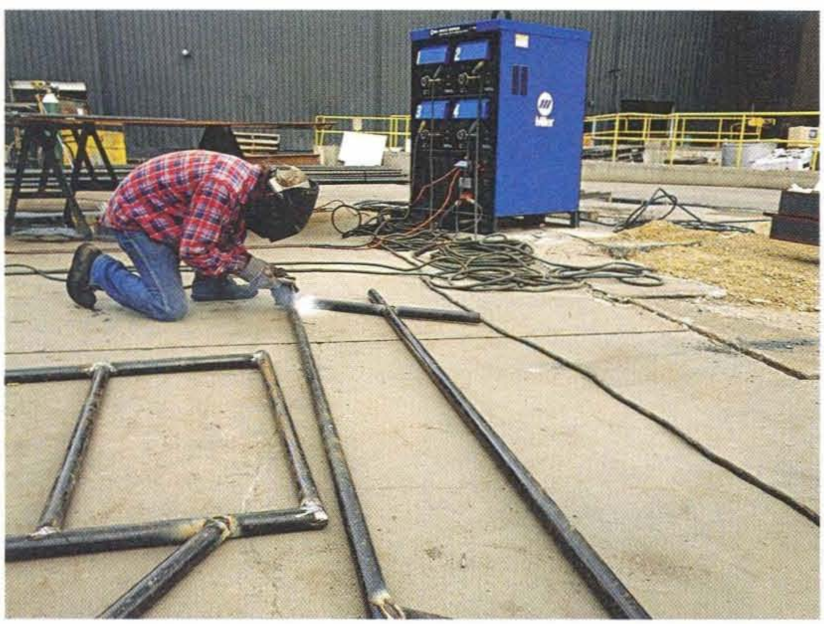
COMBINING WELD SYMBOLS

During fabrication of a product, it may be necessary to make more than one type of weld on a joint. Thus, a joint may require both a fillet and double-bevel groove weld. When more than one type of weld is required, a symbol is shown for each weld. See Figure 44-7.

Figure 44-7. *A joint that requires more than one type of weld is represented by a combined weld symbol.*

Combined Weld Symbols
Figure 44-7





Miller Electric Manufacturing Company

Weld specification is communicated to the welder by the welding symbols used on the prints.

Fillet Welds

The leg size (width) of a fillet weld is shown to the left of the weld symbol and is expressed in fractions, decimals, or metric units (mm). When both sides of a fillet are to be welded and the welds differ in dimensions, both are dimensioned. Both welds are also dimensioned if the welds have the same dimension. Where a note appears on a drawing that governs the size of a fillet weld, no dimensions are usually shown on the symbol. See Figure 44-8.

The length of the weld is shown to the right of the weld symbol by numerical values representing the actual required length. When a fillet weld with unequal legs is required, the size of both legs is placed to the left of the weld symbol with a note for clarification.

Notes are used on prints to provide additional information to the welder. Notes may be general or specific. General notes apply a given requirement to all items on the print. Specific notes apply a given requirement to a specific item on the print.

Intermittent Fillet Welds. The length and pitch increments of intermittent fillet welds are shown to the right of the weld symbol. The first figure represents the length of the weld section and the second figure represents the pitch (center-to-center spacing) between the welds. See Figure 44-9.

Groove Welds

There are several types of groove welds that may require partial or complete penetration, and a particular bevel depth. See Figure 44-10. Their effective throat sizes (in fractions, decimals, or millimeters) are as follows:

- For single-groove and symmetrical double-groove welds that extend completely through the weld parts being joined, no size is included on the welding symbol.

Fillet Weld Symbols
Figure 44-8

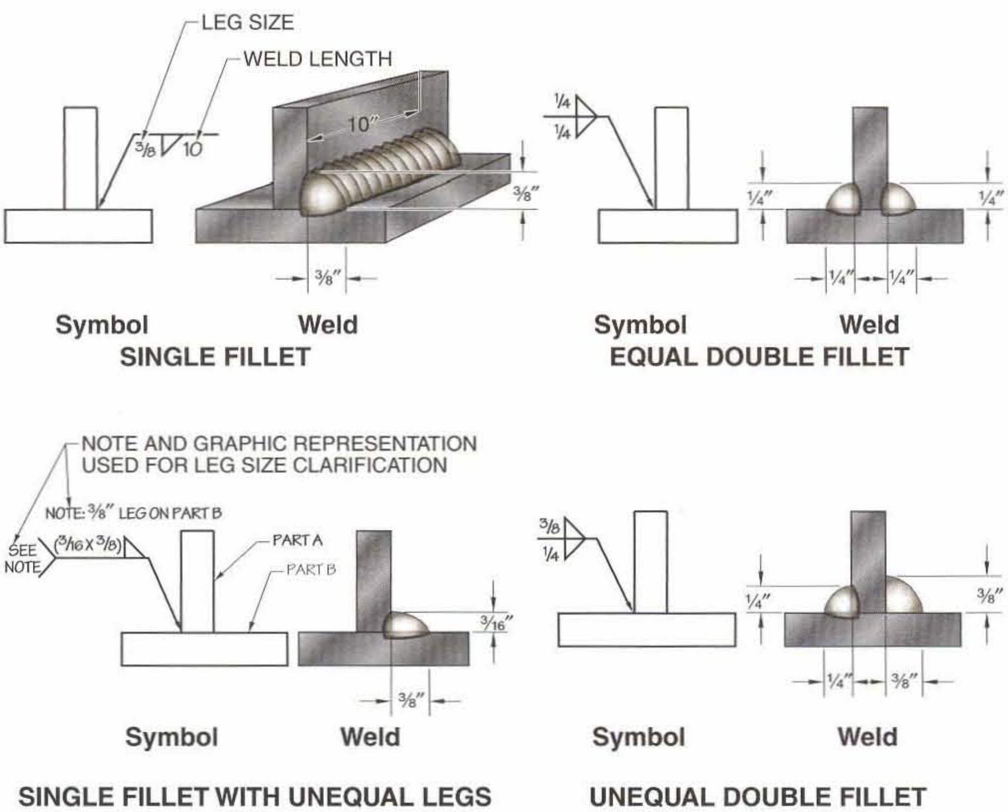


Figure 44-8. *The leg size (width) of the fillet weld is expressed as a fraction, decimal, or metric unit to the left of the weld symbol. The length is indicated by the actual numerical value to the right of the weld symbol.*

Intermittent Weld Symbols
Figure 44-9

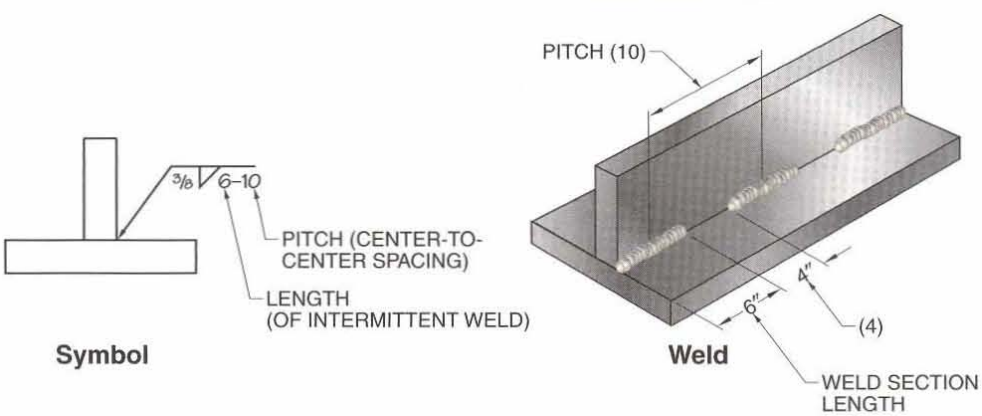


Figure 44-9. *The length and pitch increments of intermittent welds are shown to the right of the weld symbol.*

- For groove welds that extend only partly through the weld parts being joined, or on nonsymmetrical double-groove joints, the effective throat (weld size) is shown in parentheses to the left of the weld symbol.
- A dimension not in parentheses when placed to the left of the weld symbol indicates the depth of the bevel only. When both the effective throat and bevel depth are indicated, the groove bevel depth is located to the left of the effective throat size.

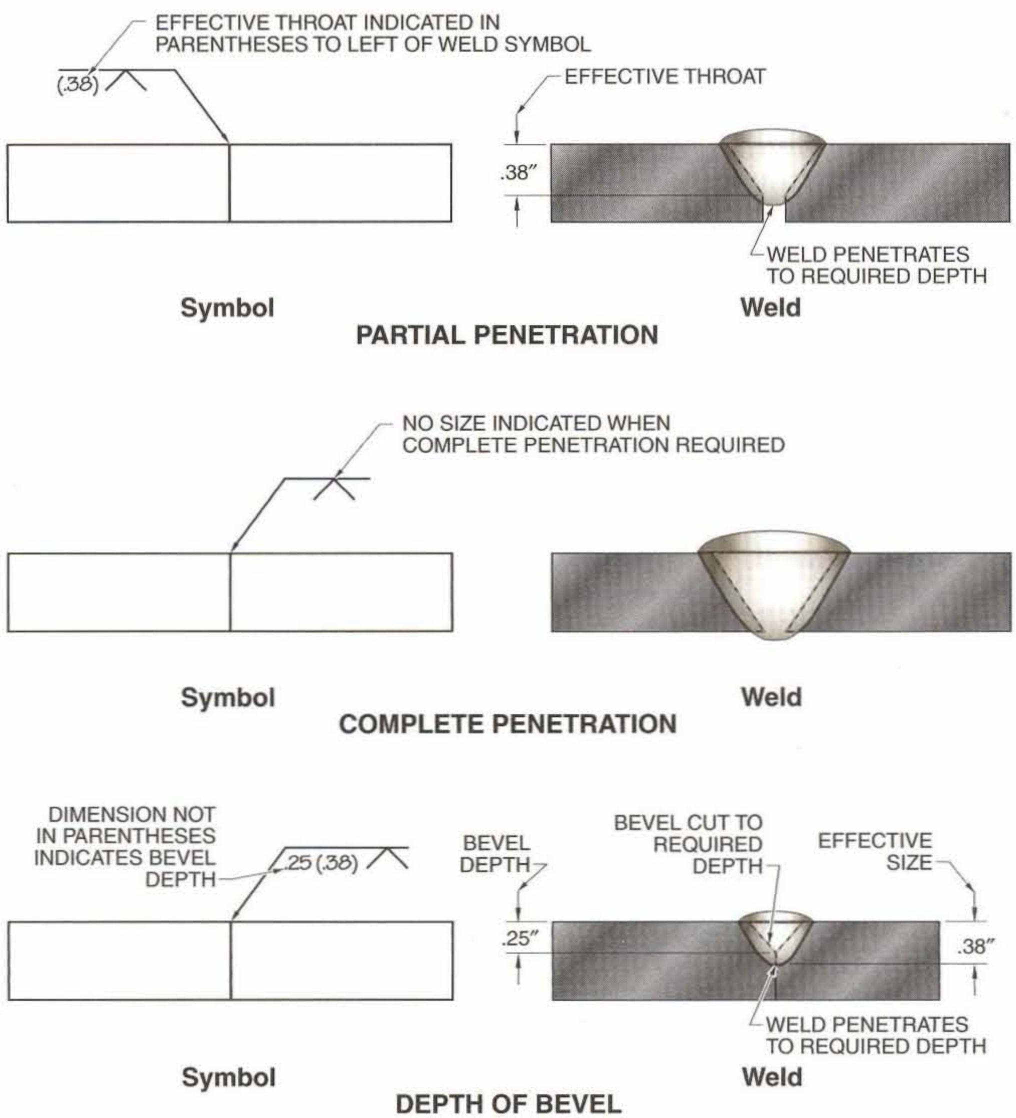
- The root opening of a square butt joint is shown inside the weld symbol. The groove angle of a bevel is indicated inside the weld symbol. The weld symbol for the bevel can be placed above or below the reference line. The arrow is pointed at the joint to be beveled. See Figure 44-11.
- The size of a flare-groove weld is considered to extend only to the tangent points as indicated by dimensional lines. See Figure 44-12.

Plug or Slot Welds

The size of a plug or slot weld is shown to the left of the weld symbol. The depth, when less than complete penetration, is shown on the inside of the weld symbol. The center-to-center spacing (pitch) is shown to the right of the weld symbol, and the groove angle of countersink is shown below the weld symbol. See Figure 44-13.

Figure 44-10. *Groove welds may require partial or complete penetration and a certain bevel depth.*

Groove Weld Symbols
Figure 44-10



Root Opening/Groove Angle
Figure 44-11

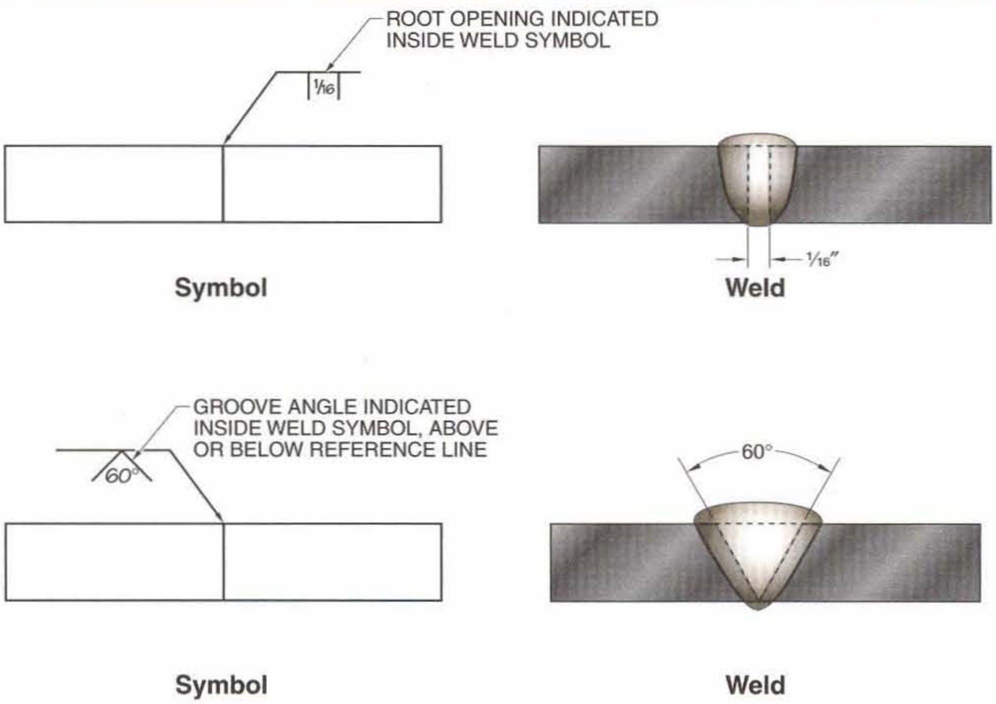


Figure 44-11. *The root opening of a square butt joint is indicated inside the weld symbol. The groove angle of a beveled groove joint can be indicated above or below the reference line.*

Flare-Groove Weld Symbols
Figure 44-12

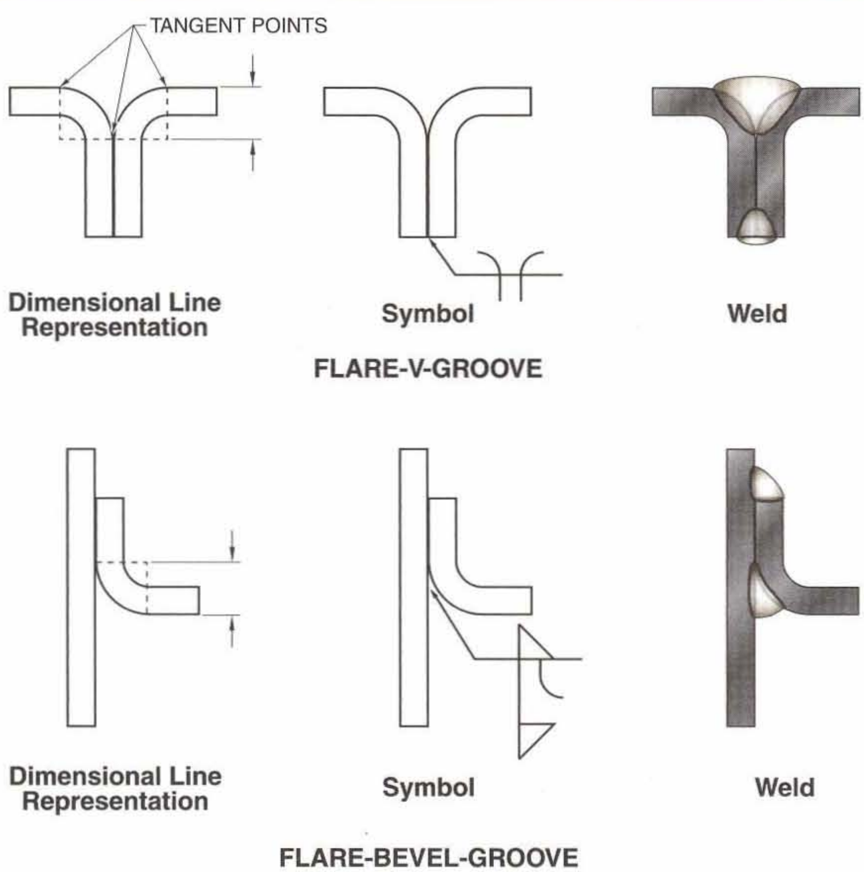
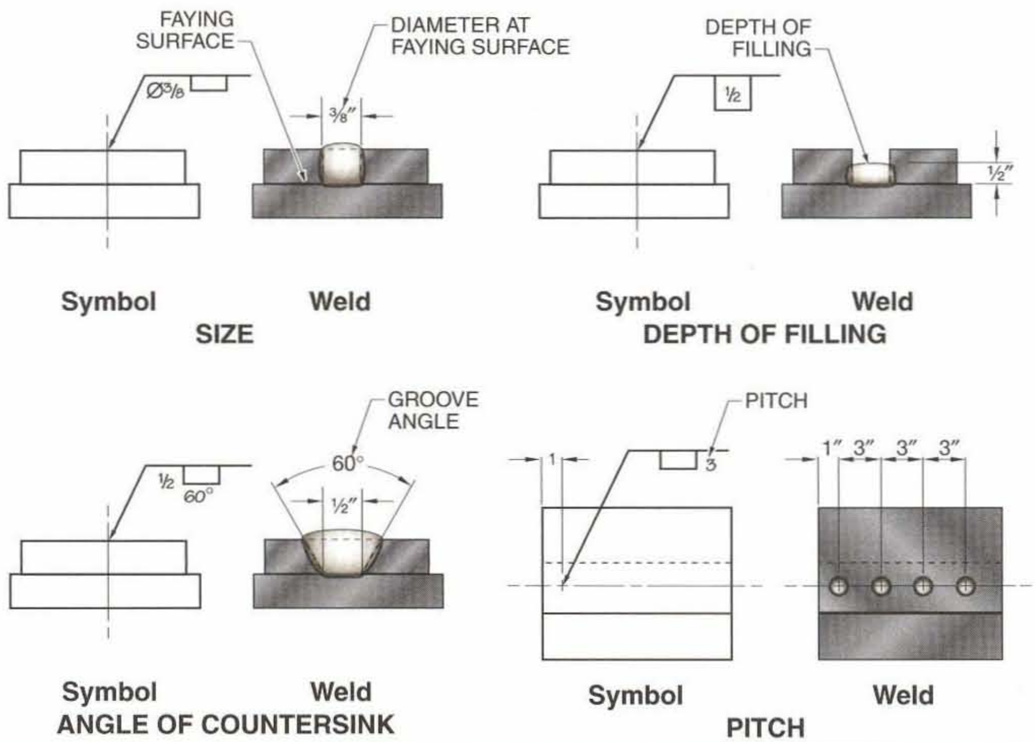


Figure 44-12. *The size of flare-V groove and flare-bevel groove welds is indicated by dimensional lines.*

Figure 44-13. *Plug weld locations are shown in varying positions around the weld symbol.*

Plug Weld Symbols
Figure 44-13



Spot or Projection Welds

Spot welds are dimensioned by either size or by strength. Size is designated as the diameter of the weld and is expressed in fractions, decimals, or millimeters, and placed to the left of the weld symbol. The strength requirement, when used, is placed to the left of the weld symbol and is expressed as the required minimum shear strength in pounds per spot weld. The spacing of spot welds is shown to the right of the weld symbol. When a definite number of spot welds are needed in a joint, this number is indicated in parentheses either above or below the reference line. See Figure 44-14.

Seam Welds

Seam welds are dimensioned either by size or by strength. Location and designation of sizes are similar to those used for fillet welds. Size is designated as the width of the weld in fractions, decimals, or millimeters, and is shown to the left of the weld symbol. The length of the weld seam is placed to the right of the weld symbol. The pitch of intermittent seam welds is shown to the right of the length dimension. See Figure 44-15.

Spot or Projection Weld Symbols
Figure 44-14

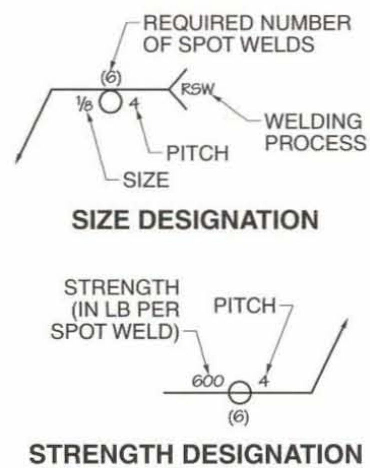
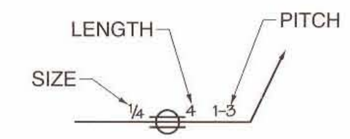
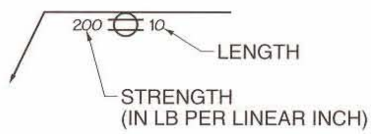


Figure 44-14. *Spot weld designations include size, strength, spacing, and number of spot welds.*

Seam Weld Symbols
Figure 44-15



SIZE DESIGNATION



STRENGTH DESIGNATION

Figure 44-15. *Seam weld designations include size, strength, length of weld seam, and pitch of weld.*

The strength of the weld, when used, is located to the left of the weld symbol, and is expressed as the minimum acceptable shear strength in pounds per linear inch.

Weld-All-Around Symbol

When a weld is to extend completely around a joint, a small circle is placed where the arrow connects the reference line. See Figure 44-16. Changes in direction of the weld require multiple arrows on the welding symbol to indicate the location of the weld. Multiple arrows are not used if the weld-all-around symbol can be used instead.

Field Weld Symbol

Welds to be made in the field (not in a shop or at the place of initial construction) are shown by a darkened triangular flag at the juncture of the reference line and arrow. The flag always points toward the reference tail of the line. See Figure 44-17.

Welds to be made in the field (not in a shop or at the place of initial construction) are shown by a darkened triangular flag at the juncture of the reference line and arrow.

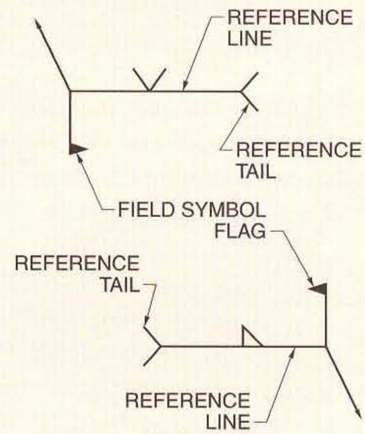
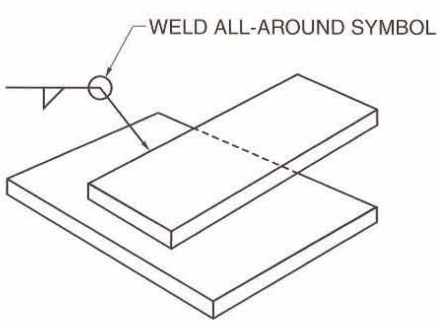


Figure 44-17. *The field weld symbol is placed at a right angle to the reference line at the junction with the arrow. The field weld symbol always faces the reference tail.*

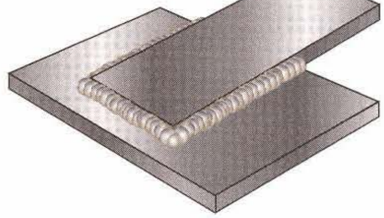
Reference Tail

The reference tail is included only when a particular welding specification, procedure, reference, weld, or cutting process needs to be called out; otherwise, it is omitted. This information is often in the form of symbols. See Figure 44-18.

Weld-All-Around Symbol
Figure 44-16



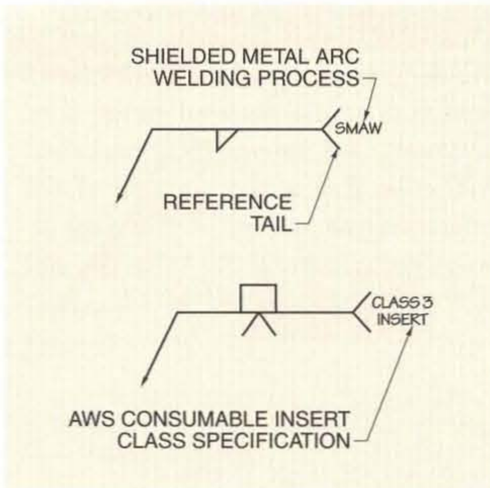
Symbol



Weld

Figure 44-16. *A small circle appears where the arrow connects the reference line to denote weld-all-around.*

Figure 44-18. *The reference tail is used when some specific detail or weld process is required.*



Abbreviations in the tail may also call out some specifications or welding processes that are included on some other part of the print. See Appendix.

Surface Contour of Welds

When bead contour is important, a special flat, concave, or convex contour symbol is added to the welding symbol. Welds that are to be mechanically finished also carry a finish symbol along with the contour symbols. See Figure 44-19.

Back Weld and Backing Weld

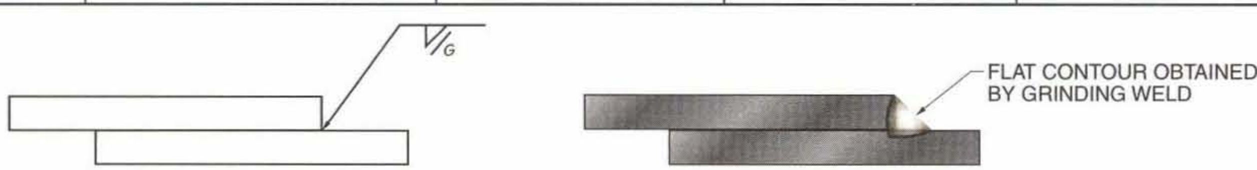
A back weld and a backing weld refer to a weld made on the opposite side of the regular weld. A back weld is made after the groove weld has been deposited. Back welds are occasionally specified to ensure adequate penetration and provide additional strength to a joint. This particular symbol is included opposite the weld symbol. Backing welds are made before a groove weld is deposited to prevent excessive penetration of the weld metal. No dimensions of back or backing welds except height of reinforcement are shown on the welding symbol. See Figure 44-20.

Melt-Thru Welds

When complete joint penetration of the weld through the metal is required in welds made from one side only, a special melt-thru weld symbol is placed opposite the regular weld symbol. No dimension of melt-thru, except height of reinforcement, is shown on the welding symbol. See Figure 44-21.

SURFACING CONTOURS

LETTER	MECHANICAL METHOD	SYMBOL		
		Flat	Convex	Concave
C	Chipping	C	C	C
H	Hammering	H	H	H
G	Grinding	G	G	G
M	Machining	M	M	M
R	Rolling	R	R	R
U	Unspecified	U	U	U



Symbol

Weld

Figure 44-19. *A flat, concave, or convex symbol added to the welding symbol indicates how the surface should be contoured.*

Back or Backing Weld Symbol
Figure 44-20

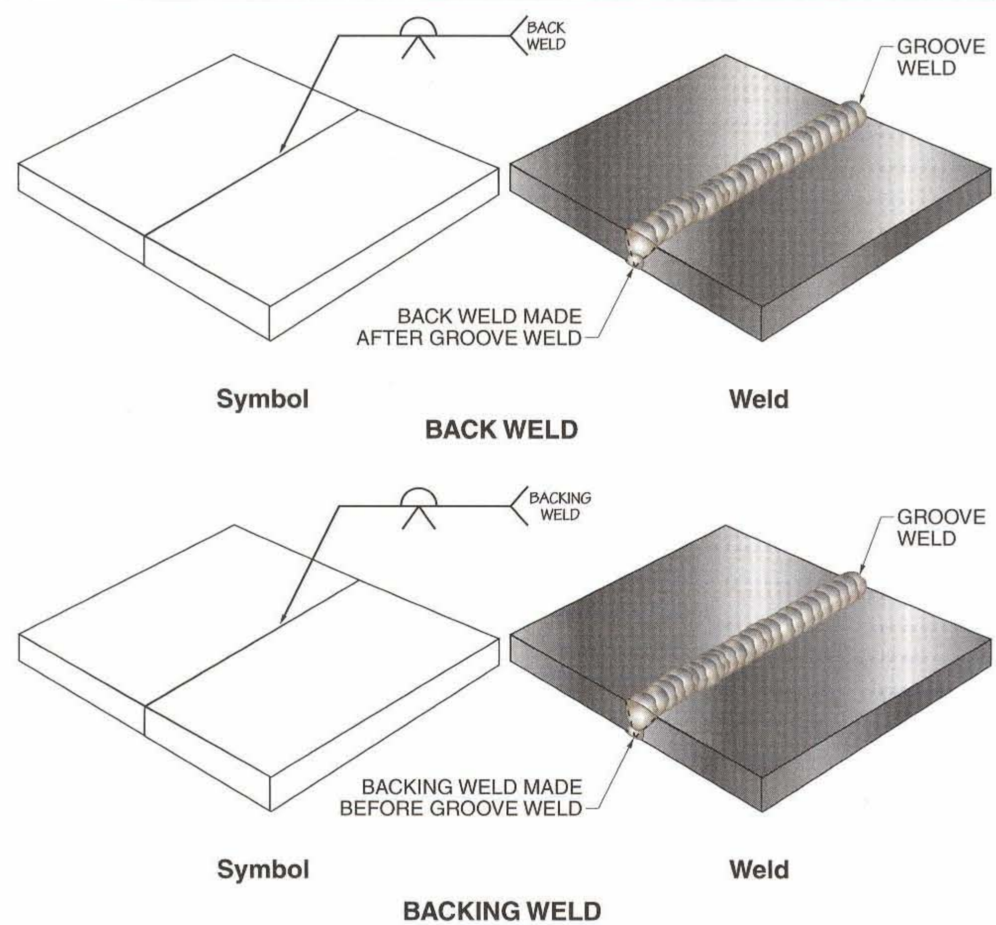


Figure 44-20. *The back or backing weld symbol is included opposite the weld symbol, with a note included in the reference tail.*

Melt-Thru Weld Symbols
Figure 44-21

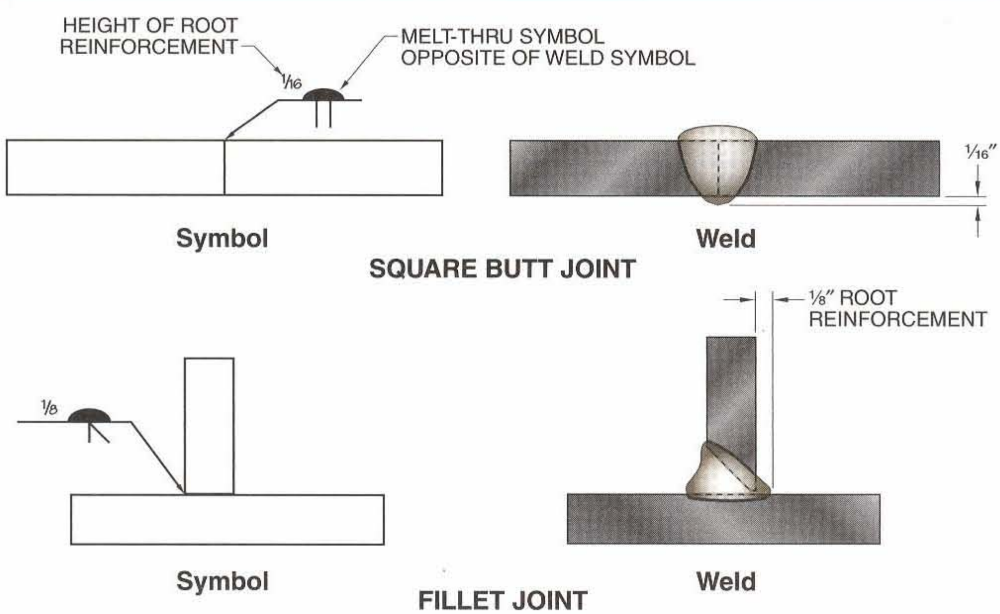


Figure 44-21. *A melt-thru symbol indicates that complete joint penetration of the weld is required from one side only.*

Surfacing Welds

Welds whose surfaces must be built up by single- or multiple-pass welding are denoted by a surfacing weld symbol. The height of the built-up surface is indicated by a dimension placed to the left of the surfacing symbol. See Figure 44-22. The extent, location, and orientation of the area to be built up are normally indicated on the drawing.

NONDESTRUCTIVE EXAMINATION SYMBOLS

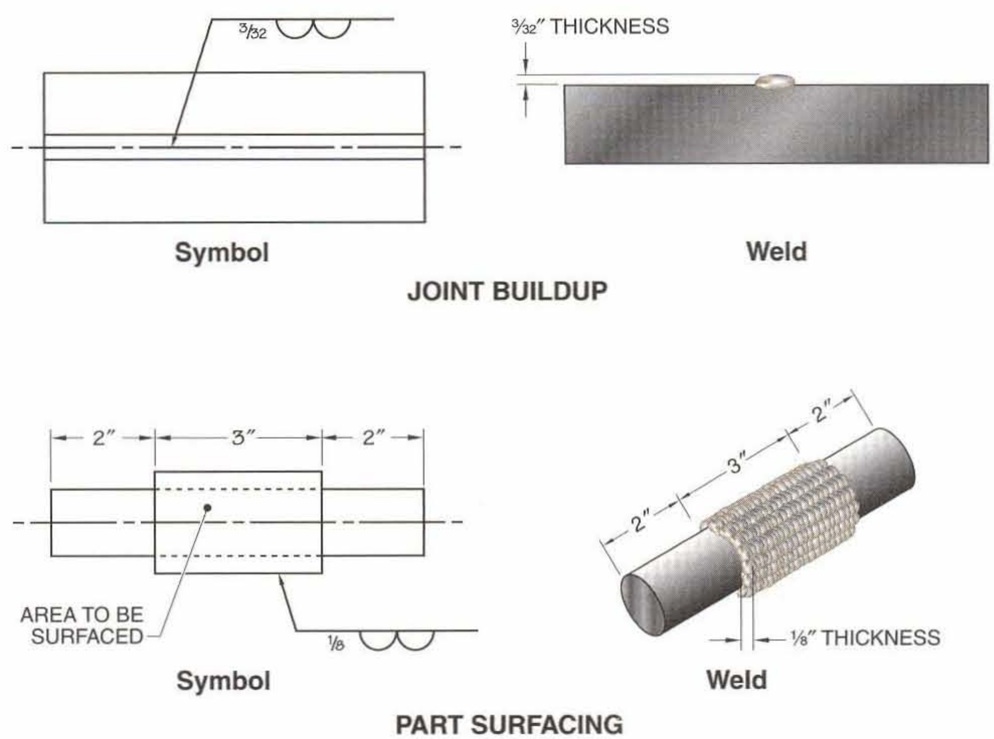
Nondestructive examination (NDE) symbols are symbols that specify examination methods and requirements to verify weld quality.

Nondestructive examination (NDE) symbols are symbols that specify examination methods and requirements to verify weld quality. The method of examination required can be specified on a separate reference line of the welding symbol or as a separate NDE symbol.

Whether the NDE method is specified on the same reference line as the weld symbol or on a separate reference line, the order of operations is the same as for multiple welding operations. The reference line furthest from the arrowhead indicates the last operation to be performed. The operation on the reference line nearest the arrowhead is performed first. When used separately, NDE symbols include an arrow, reference line, examination letter designation, dimensions, areas, number of examinations, supplementary symbols, tail, and specifications and other references. See Appendix.

Figure 44-22. *A surfacing weld symbol, with the required dimension placed to the left, indicates that surfaces are to be built up by welding.*

Surfacing Welds
Figure 44-22

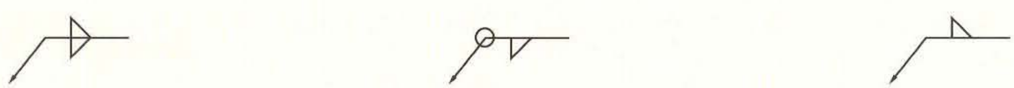


POINTS TO REMEMBER

1. A welding symbol is a graphical representation of the specifications for producing a welded joint.
2. Instructions regarding the type of weld are indicated either above or below the reference line.
3. The arrow side is the surface that is in the direct line of vision of the welder. The other side is the opposite surface of the joint.
4. When more than one type of weld is required, a symbol is shown for each weld.
5. Welds to be made in the field (not in a shop or at the place of initial construction) are shown by a darkened triangular flag at the juncture of the reference line and arrow.
6. Nondestructive examination (NDE) symbols are symbols that specify examination methods and requirements to verify weld quality.

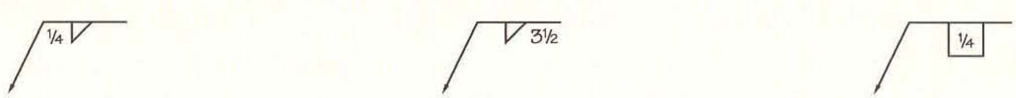
QUESTIONS FOR STUDY AND DISCUSSION

1. What is meant by the arrow side of the welding symbol?
2. What is meant by the other side of the welding symbol?
3. Indicate the meaning of the following welding symbols.

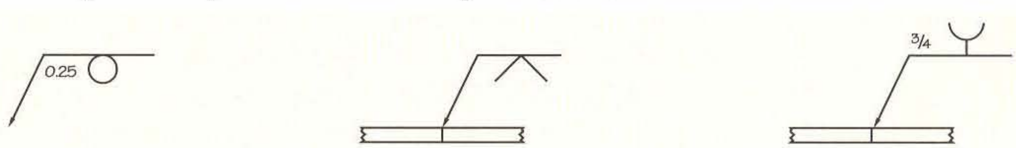


4. What type of weld do these symbols indicate?

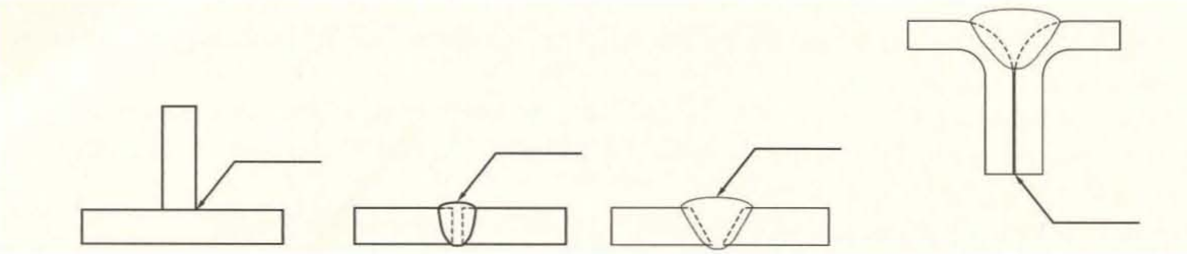
5. These symbols represent what weld specifications?



6. These symbols represent what weld specifications?

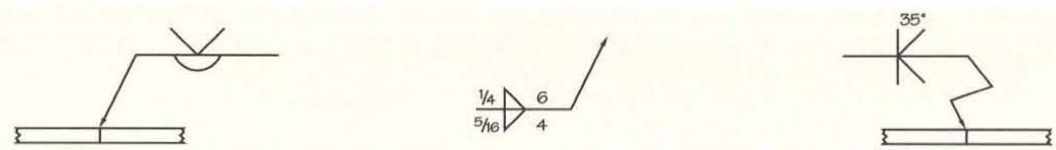


7. Draw completed welding symbols, including necessary information, to describe the following welds.

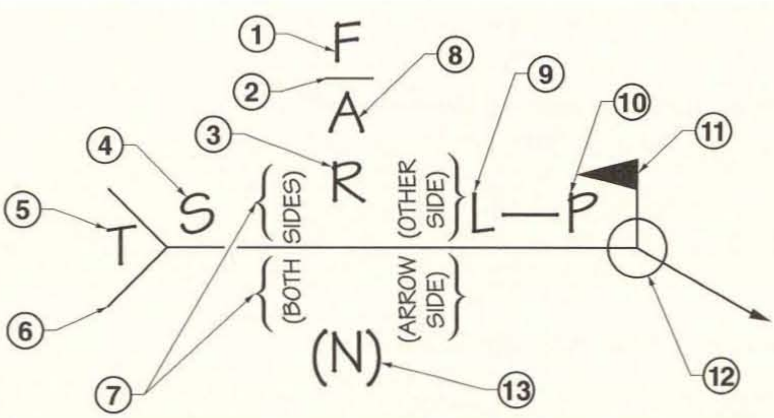


8. What do these welding symbols mean?

9. What do these welding symbols represent?



10. Using the appropriate table in the appendix, identify the parts of the master welding symbol shown.



45 Materials & Fabrication Standards & Codes

Welding Technology

Materials and fabrication standards and codes provide a common language for ensuring consistency among products of various manufacturers. Purchase orders for materials must refer to materials standards. Certification accompanying products must be checked to ensure that the materials conform to indicated standards. Fabrication standards and codes ensure that materials and welded products meet specified mechanical property and quality requirements.

Quality requirements specified in materials and fabrication standards and codes are accepted by manufacturers, suppliers, and users as the basis for ordering and fabricating materials. The steps involved in specifying, procuring, and fabricating materials are addressed by materials and fabrication standards and codes.

Quality requirements for welding are based on the possible risks and consequences of failure of the equipment or component. Quality requirements for welding are established by industry groups and ensure the necessary quality at a reasonable cost.

MATERIALS STANDARDS

Materials standards are classified according to the kind of information they contain. Various organizations are responsible for the development of materials standards. Materials standards are developed and reviewed by qualified people organized into committees of producers, end users, and general interest groups.

Classification of Materials Standards

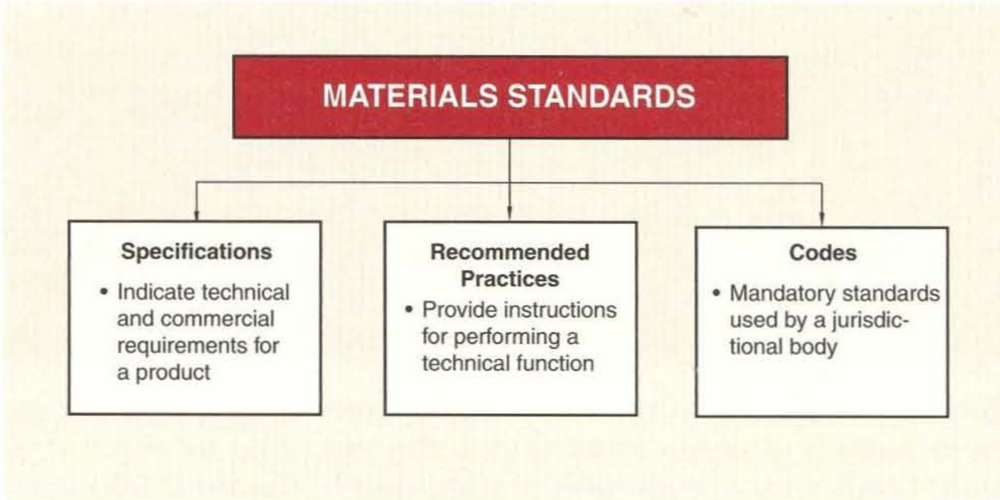
A *standard* is a document that, by agreement, serves as a model for the measurement of a property or the establishment of a procedure. "By agreement" means that all parties involved in the product, including manufacturers, suppliers, and end users, must agree to the use of the standard as being fair and practical. Materials standards are classified as specifications, recommended practices, and codes. See Figure 45-1.

A *specification* is a type of standard that indicates the technical and commercial requirements for a product. Material requirements are most often described by means of specifications. For example, ASTM A36 is a specification for structural steel members used in riveted, bolted, or welded construction of bridges and buildings, and for general structural purposes. ASTM A36 indicates acceptable methods of manufacture and minimum acceptable properties of structural steel members.

A *recommended practice* is a type of standard that provides instructions for performing one or more repetitive technical functions. For example, ASTM E165 is a recommended practice for conducting liquid penetrant testing. ASTM E165 indicates standard test parameters that should be followed to allow comparison between liquid penetrant tests performed on different welds or other items.

Materials standards and codes are developed by consensus (agreement) between parties representing producers, end users, and general interest groups.

Figure 45-1. *Materials standards are classified as specifications, recommended practices, and codes.*



Codes are mandatory standards that have been adopted by a jurisdictional body.

A *code* is a type of standard that is mandatory and is used by a jurisdictional body. A code indicates what "shall" be done rather than what "may" be done. For example, ASME (American Society of Mechanical Engineers) International administers the code for pressure piping. The code for pressure piping covers specific types of piping, such as for steam or petroleum products, and contains regulations for the design and fabrication of piping for the specific service category to achieve safe and reliable operation.

Standards types include specifications, recommended practices, and codes.

Standards Development

Standards are developed by standards committees. Standards committees consist of a balanced representation of producers, end users, and certain general interest groups to represent all interested parties. See Figure 45-2. Balanced representation ensures that standards are created that are acceptable to all representatives. Standards committees meet regularly, generally every six months, to consider actions on standards for which they are responsible. Actions on standards include new standards development or revision of existing standards.

Two types of activity in standards creation are new standards development and existing standards revision.

New Standards Development. New standards development is initiated by task groups within standards committees. New standards development is a relatively slow and deliberate process. The objective is to create documents that are acceptable to the majority of producers and end users whose businesses are affected by them.

Task groups develop draft documents. Draft documents are the starting point for new standards. The applicable standards committee reviews the draft document and suggestions for improvement are balloted by the committee. *Balloting* is a formal method of documenting and voting upon the reviewers' suggestions. Once the draft document is revised according to the ballot, the task group is disbanded. The revised draft standard becomes the responsibility of the standards committee. See Figure 45-3.

It is not necessary to ballot all reviewers' suggestions. For example, editorial content items and nonrelevant technical suggestions are not necessarily balloted. Editorial content items are proposed segments of a standard that do not affect technical content. Nonrelevant technical suggestions are proposed segments of a standard which, although technical, are not within the scope of the standard.

Several ballots are usually required before a draft standard is ready for review outside the standards committee. Outside review is also done through balloting. Supplementary review(s) may result in the standard being returned to the committee for further work, and so on.

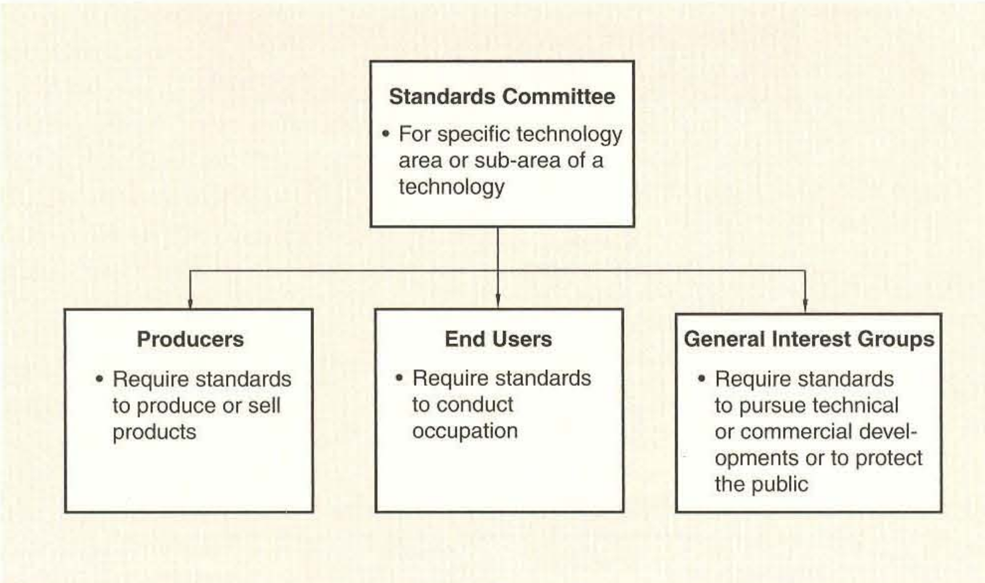


Figure 45-2. *Standards committees consist of a balanced representation of producers, end users, and certain general interest groups to represent all interested parties.*

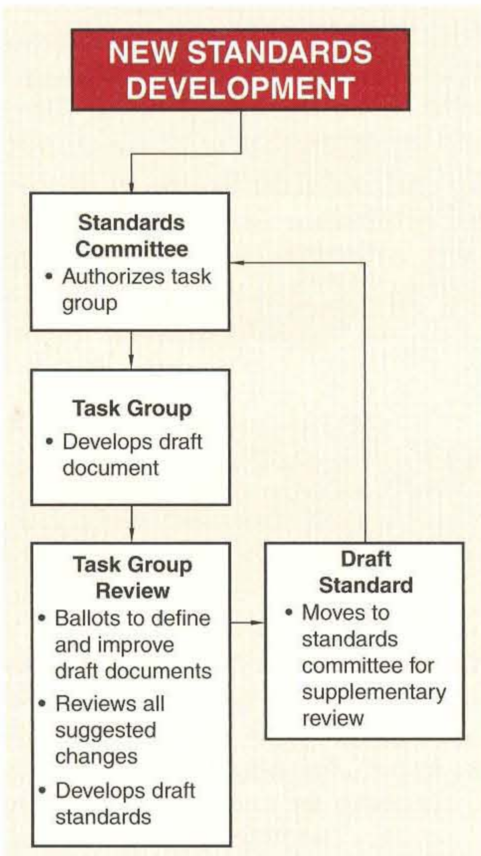


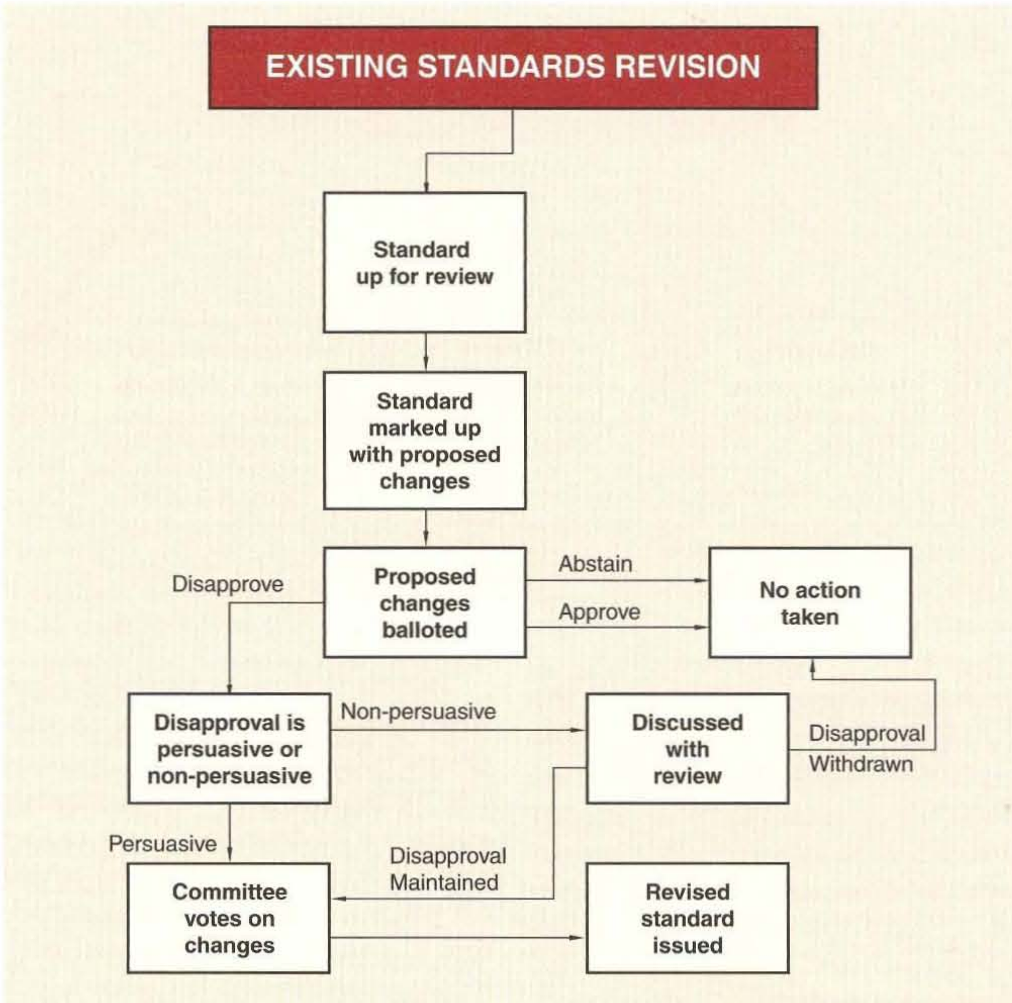
Figure 45-3. *The objective of new standards development is the creation of documents that are acceptable to the majority of producers and users whose business is affected by them.*

Existing Standards Revision. Existing standards revision is the job of the responsible committee. If necessary, responsibility may be transferred to another committee more closely aligned with the contents of the standard.

Standards must be reviewed regularly to maintain their relevance to current technical and commercial practices. The formal time interval for standards review varies from two years to five years, although review may be carried out whenever there is anything significant to address. The process for existing standards revision is similar to that for new standards development. However, existing standards revision is usually confined to specific segments of the existing standard that may have become irrelevant or obsolete through changes in technical or commercial practices. The specific segments are revised and balloted. See Figure 45-4.

The balloting process for existing standards revision is more rapid than new standards development because fewer parts of the existing standard are reviewed. If the entire standard is acceptable without changes, it is reissued as a reaffirmed standard. If the standard is modified, it is issued as a revised standard. Reaffirmed or revised standards carry the most current date or revision number. The latest issue of any standard supercedes previous issues. This rule applies to most, but not necessarily all, standards. Work with the latest issue of any standard, unless otherwise directed.

Figure 45-4. *Existing standards revision is usually confined to specific segments of an existing standard that may have become irrelevant or obsolete through changes in technical or commercial practices.*



User Enquiry

A *user enquiry* is a formal procedure developed by standards committees and code-creating organizations to help users interpret issues and offer suggestions. The intent of all user enquiry procedures is to maintain a channel of official communication between a standard- or code-writing committee and end users on questions or problems arising from the use of a standard or code. User enquiry procedures include scope, purpose, content, and proposed reply.

- Scope identifies the segment of the standard or code relevant to the enquiry. One item is addressed per enquiry.
- Purpose states the intent of the user enquiry—for example, to obtain an interpretation of a code requirement or to request revision of a particular segment of a standard.

Users who wish to make recommendations for revisions to standards usually do so through an approved query form or data form supplied by the standards organization.

- Content lists relevant paragraphs, figures, sketches, and tables in the code or standard that bear upon the user enquiry, with complete documentation to permit the standards committee to quickly and fully understand the enquiry. Technical justification must be provided if the user wants to obtain revision of the standard or code.
- Proposed reply to the user enquiry should be indicated when necessary. For example, when a revision of a particular segment of the standard is requested, the wording of a proposed revision must be supplied by the end user proposing the change.

The result of a user enquiry may be a temporary addendum to the standard or code to permit usage of the suggested modification. Temporary addenda contain a time limit for the proposed modification before it is formally balloted as a revision to the current version of the standard or code.

MATERIALS STANDARDS ORGANIZATIONS

Materials standards organizations that produce standards for base metals and welding consumables include ASTM International (ASTM), the Society of Automotive Engineers (SAE), Aerospace Material Specifications (AMS), the American Welding Society (AWS), ASME International, the American Petroleum Institute (API), and the American National Standards Institute (ANSI). Additionally, the Canadian Standards Association (CSA), the European Standards Council (CEN), and the International Organization for Standardization (ISO) develop standards globally, or for other countries.

ASTM International (ASTM)

ASTM International is the largest source of materials standards. From the work of over 130 standards-writing committees, ASTM International publishes standard test methods, specifications, practices, guides, classifications, and terminology. ASTM International standards cover metals, paints, plastics, textiles, petroleum, construction, energy, the environment, consumer products, medical services and devices, computerized systems, and electronics. ASTM International has no technical, research, or testing facilities. Such work is done voluntarily by 35,000 technically qualified ASTM International members worldwide.

More than 9100 standards are published each year in 70 volumes of the *Annual Book of ASTM Standards*. These standards and related information are sold worldwide. ASTM International standards used for base metals in welding contain information on the manufacturing practices and performance characteristics of materials in various product forms such as plate, bar, pipe, and rod.

Standards organizations may develop standards that are applicable in their home country only, or, as in the case of ASTM International, that have been adopted worldwide.

ASTM International Standards Designation. The ASTM International standards designation is based on a letter-number combination, such as A36 or B315. If the standard is tentative (issued on a trial basis), the year is followed by the letter T. If the standard is revised a second time in the same year, the date is followed by the letter a. If it is revised a third time in the same year, the date is followed by the letter b, etc. If the standard is a metric equivalent of another standard, the serial number is followed by an M. A *metric equivalent standard* is a version of a standard in which all the units are indicated in metric (SI) values. See Figure 45-5.

Embedded designations are unique materials identifications that are part of the standard. In most cases, an embedded designation must be coupled with ASTM International or other specification number to uniquely define a material. ASTM International and other materials standards usually refer to several different materials that are described by the prefix, grade, type, or class followed by a unique designation. For example, ASTM A193 is a specification for alloy and stainless steel bolting materials. However, to specify ASTM A193 alone is not enough. ASTM A193 includes embedded materials such as:

- Grade B7 (high-strength, low-alloy steel)
- Grade B8 class 1 (304 annealed stainless steel)
- Grade B8 class 2 (304 cold worked stainless steel)

Various industry groups write materials standards and codes, but the largest set of standards is produced by ASTM International (ASTM).

ASTM International Standards Designations
Figure 45-5

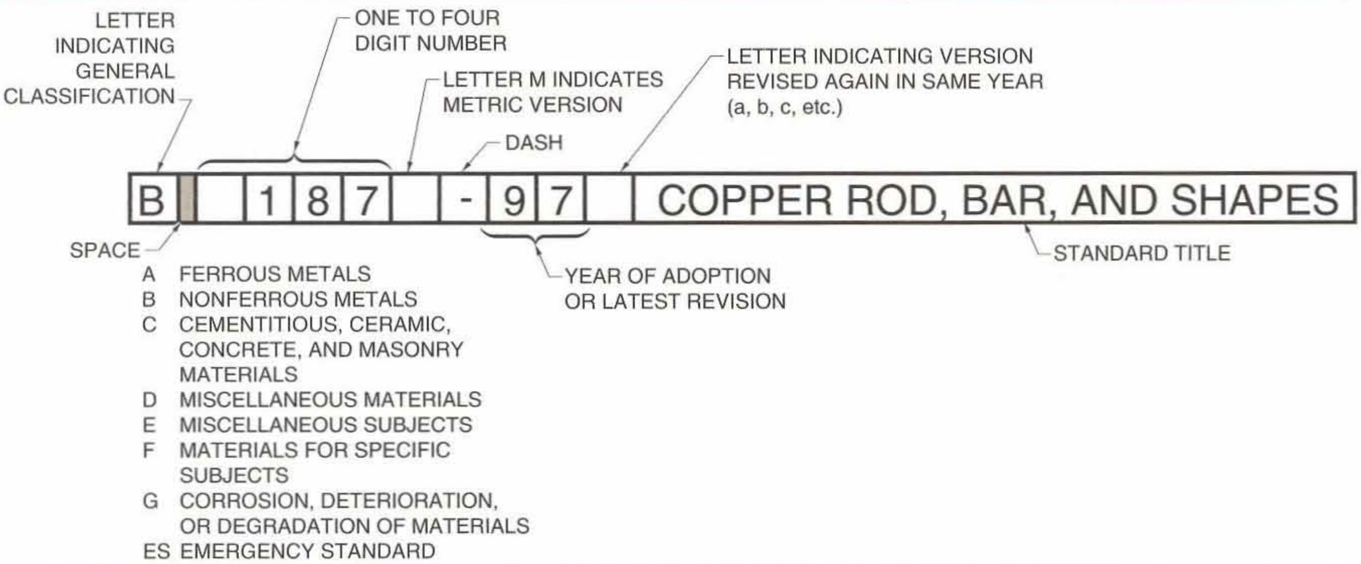


Figure 45-5. *The ASTM International standards designation is based on a letter-number combination.*

Standards pertaining to welding are published by AWS and cover welding processes, filler metals, and health.

Unified Numbering System. The *unified numbering system (UNS)* is a common embedded designation system that unifies all families of metals and alloys. The UNS uniquely identifies the chemical composition of alloys that have been fixed by other specification bodies. If the alloy is proprietary (produced by a limited number of suppliers), the chemical composition is established by the producer. The UNS consists of a capital letter followed by five numbers. The capital letter identifies the alloy family and, where possible, the five numbers are related to the pre-UNS designation of the alloy. See Figure 45-6.

Society of Automotive Engineers (SAE) and Aerospace Material Specifications (AMS)

The Society of Automotive Engineers (SAE) and Aerospace Material Specifications (AMS) follow standards for engineering materials used in on- and off-road vehicles, aircraft, and spacecraft. The SAE is a major source of technical information and expertise used in designing, building, maintaining, and operating self-propelled vehicles, whether land-, sea-, air-, or space-based. SAE collects, organizes, stores, and disseminates information on cars, trucks, aircraft, space vehicles, marine equipment, and engines of all sizes.

SAE and AMS standards are administered by SAE and describe quality levels required for end use. AMS standards generally contain the most stringent quality requirements of any standards because they define the requirements for use in extremely critical services. AMS standards may be used in applications outside of the aerospace industry where stringent quality requirements justify the additional cost. For example, critical forgings for extreme cyclic (fatigue) applications may require materials manufactured to AMS specifications because the high degree of internal cleanliness required of materials that meet AMS specifications ensures high fatigue resistance.

American Welding Society (AWS)

American Welding Society (AWS) standards cover automatic, semiautomatic, and manual welding, as well as brazing, soldering, ceramics, lamination, robotics, and safety and health issues. AWS is organized into more than 180 committees, 125 of which are technical committees, involving 1400 members in the production of standards.

UNIFIED NUMBERING SYSTEM	
UNS Number	Type of Metal
Axxxxx	Aluminum and Aluminum alloys
Cxxxxx	Copper and Copper alloys
Exxxxx	Rare Earth and similar metals and alloys
Fxxxxx	Cast Irons
Gxxxxx	AISI and SAE Carbons and alloy Steels
Hxxxxx	AISI and SAE H-Steels
Jxxxxx	Cast Steels (except tool steels)
Kxxxxx	Miscellaneous Steels and ferrous alloys
Lxxxxx	Low melting metals and alloys
Mxxxxx	Miscellaneous nonferrous metals and alloys
Nxxxxx	Nickel and Nickel alloys
Pxxxxx	Precious metals and alloys
Rxxxxx	Reactive and refractory metals and alloys,
Sxxxxx	Heat and corrosion resistant steels (including stainless) Valve Steels, and Iron-base "superalloys"
Txxxxx	Tool Steels, wrought and cast
Wxxxxx	Welding filler metals
Zxxxxx	Zinc and Zinc alloys

Figure 45-6. *The unified numbering system consists of a capital letter followed by five numbers. The capital letter identifies the alloy family and the five numbers indicate the pre-UNS designation of the alloy.*

AWS standards also cover welding consumables. Filler metals are one category of welding consumables. Most commercial filler metals are identified by an AWS designation. Whenever possible, welding consumables should be referred to by AWS designations rather than commercial names.

Welding consumable requirements are standardized by AWS in a series of specifications based on the material family. For example, AWS A5.1 describes standard carbon steel covered arc welding electrodes. Embedded welding consumables are identified by letter-number designations within each specification.

AWS specifications indicate chemical compositions of materials and mechanical properties of the deposited weld metal using standardized welding procedures in a specified joint detail to produce weld specimens for testing. When required, specifications may also indicate other properties such as toughness or an acceptable amount of porosity. Most specifications include usability parameters such as the weld position for which the filler metal is designed, welding current that should be used, and in the case of covered electrodes, the type of coating. Size and packaging information is also provided. AWS publication FMC: *Filler Metal Comparison Charts,* lists commercial names for AWS filler metal designations. See Figure 45-7.

The AWS identification of welding filler metals consists of letters and numbers. The letters include R for rod, E for electrode, RB for rod or wire, and ER for electrode rod or wire. Rod is welding wire that is cut and straightened. Rod may be flux-coated or bare. Electrodes may be flux cored (tubular), consisting of a metal sheath packed with fluxes and alloying elements. Fluxes, when used separately from filler metals, are also classified. Since the welding consumable identifications embedded within AWS specifications are unique, they are often referred to without their specification number, such as E7018 or ER308.

ASME International (ASME)

ASME International publishes codes and standards for the design, manufacture, and installation of mechanical devices.

A5.1, CARBON STEEL Covered Arc Welding Electrodes

See ANSI/AWS A5.1, Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding

E6010

SOURCE	PRODUCT
AIR LIQUIDE CANADA INC.	LA 6010
Airco Filler Metals	Pipe-Craft
American Filler Metals Company	AFM 6010
American Welding Alloys	AWA 6010
Arcweld Products, Ltd.	EASYARC 10, EASYARC 10+
Askaynak Kaynak Teknigi Sanayi Ticaret A.S.	AS S-6010
Bohler Thyssen Welding USA, Inc.	Thyssen Cel 70, Bohler Fox Cel
CARBO-WELD Schweissmateriallen GmbH	CARBO RC 3
Champion Welding Products	CHAMPION E6010
D&H Secheron Electrodes Limited	CELLUTHERME
Electromanufacturas S.A.	West Arco XL-610, ZIP 10-T, West Rode 600/10
ESAB AB	Pipeweld 6010
ESAB WELDING & CUTTING PRODUCTS	SUREWELD 10-P, SUREWELD AP-100
EXSA S.A. - División Soldaduras OERLIKON	Cellocord P, PT
EXSA S.A. - División Fontargen	FON E 51 A, FON E 51 AT
HILARIUS HAARLEM HOLLAND BV	HILCO Pipeweld 6010
Hobart Welding Products	PIPEMASTER 60
HYUNDAI WELDING PRODUCTS, INC.	S-6010 D
Indura S.A. Industria y Comercio	INDURA 6010
Industrial Welding Corporation	NIHONWELD N-6010

American Welding Society

Figure 45-7. *AWS publication* FMC: Filler Metal Comparison Charts, *lists commercial names for AWS filler metal designations.*

ASME International Boiler and Pressure Vessel Code materials utilize selected ASTM and AWS specifications for base metals and welding consumables, but with minor changes to those specifications where they are too broad for boiler and pressure vessel applications. ASME International Boiler and Pressure Vessel Code-approved materials and welding consumables are assigned the prefix letter S to indicate approval. Only ASME Code-approved materials and welding consumables may be used for fabrication or repair of equipment built to the ASME International Boiler and Pressure Vessel Code.

ASME Pressure Piping Code materials carry ASTM and AWS specifications for base metals and welding consumables, respectively. Specific ASME pressure piping codes indicate which ASTM and AWS specifications are approved.

The ASME International Boiler and Pressure Vessel Code consists of 11 Sections. Each Section covers aspects of design, fabrication and inspection, care and operation, materials specifications, nondestructive testing, and welding and brazing qualifications. Some Sections consist of sub-parts known as Divisions.

The ASME International Boiler and Pressure Vessel Code is unique in that it requires third-party inspection independent of the fabricator and the user. Inspectors are commissioned by examination by the National Board of Boiler and Pressure Vessel Inspectors (NB). These authorized inspectors (AI) are employed by inspection agencies such as insurance companies or jurisdictional authorities. Users who are qualified to carry out pressure vessel fabrication and repair submit applications to have their own third-party inspectors, or owner-user inspectors.

A company must exhibit a quality control system and quality manual before fabricating a boiler or pressure vessel. The quality control system is audited by the authorized inspection agency and either the jurisdictional authority or the National Board. Based on successful audit of the fabricator's quality system, ASME International may issue the fabricator a Certificate of Authorization and a code symbol stamp. The authorized inspection agency is involved in monitoring fabrication and field erection of boilers and pressure vessels. The AI must be satisfied that all applicable provisions of the ASME International Boiler and Pressure Vessel Code have been followed before allowing the fabricator to apply its code symbol stamp to the vessel nameplate.

Manufacturers and contractors who regularly build or install pressure vessels or pressure piping are required to have an ASME International symbol stamp, indicating they have been approved by ASME International as an authorized manufacturer of the type of equipment specified. Symbol stamps consist of letters designating the type of construction permitted.

American Petroleum Institute (API)

The American Petroleum Institute (API) develops materials standards applicable to petroleum storage and natural gas and petroleum transmission by pipeline. Pipe steels are low-carbon steels used in the oil and gas industries and include drill pipe, casing, tubing, and line pipe. API 5D, *Specification for Drill Pipe,* covers drill pipe. Casing is used to structurally restrain the walls of oil wells or gas wells, to exclude undesirable fluids, and to confine oil or gas to subsurface layers. Tubing is used within the casing of oil wells to conduct oil and gas to ground level. API 5CT, *Specification for Casing and Tubing,* covers casing and tubing. Line pipe (transmission pipe) is welded or seamless pipe used principally for conveying gas and oil. API 5L, *Specification for Line Pipe,* covers line pipe.

American National Standards Institute (ANSI)

The American National Standards Institute (ANSI) is a standards organization that adopts standards written and approved by member organizations. ANSI connects its member organizations by unifying their adopted standards. ANSI standards have been formally adopted at the national level. ANSI functions as coordinator of American national standards. ANSI also manages United States participation in international standards activities. An ANSI-approved standard retains its sponsor organization designation but additionally carries on the title page a descriptor indicating it is an American National Standard. For example, ASTM A36/A36M, *Standard Specification for Carbon Structural Steel,* is also an ANSI standard.

Canadian Standards Association (CSA)

The Canadian Standards Association (CSA) develops standards and certification requirements used throughout Canada. See Figure 45-8. CSA standards for filler metals are in general agreement with AWS specifications. Since Canada uses the metric (SI) system of units, the familiar AWS embedded designations such as E60XX or E70XX that are related to the tensile strength of the filler metal in ksi are changed to three-digit numbers corresponding to tensile strength in megapascals (MPa). CSA standards also indicate the diameter of the core wire in millimeters (mm).

Figure 45-8. *The Canadian Standards Association (CSA) develops standards and certification requirements used throughout Canada.*

CANADIAN STANDARDS	
Number	**Title**
CSA W47.1	"Certification of Companies for Fusion Welding of Steel Structures"
CSA W47.2	"Aluminum Welding Qualification Code"
CSA W117.1	"Code for Safety in Welding and Cutting (Requirements for Welding Operators)"
CSA W178	"Qualification Code for Welding Inspection Organizations"
CSA W55.3	"Resistance Welding Qualification Code for Fabricators of Structural Members Used in Buildings"
CSA S244	"Welded Aluminum Design and Workmanship (Inert Gas Shielded Arc Process)"
CSA W59	"Welded Steel Construction (Metal Arc Welding)"
CSA W48	"Welding Electrodes"
CSA W186	"Welding of Reinforcing Bars in Reinforced Concrete Construction"

Purchase orders for materials refer to applicable materials standards and codes.

European Standards Council (CEN)

European standards are produced by the European Standards Council (CEN) and are known as Euronorms. Euronorms have the prefix letters EN. Euronorms replace the standards of the individual countries of the European Community with single documents for specific items such as various base metals and filler metals.

International Organization for Standardization (ISO)

The International Organization for Standardization (ISO) promotes the development of standards to facilitate the international exchange of goods and services. ISO publishes several standards on welding electrodes.

USING MATERIALS STANDARDS

Materials standards provide information on commercially available base metals and welding consumables. The variations between materials standards permit specification and procurement consistent with the design and service requirements of the fabrication. Certification of products ensures that materials procured for welding and fabrication meet the specifications. The relatively high temperatures and stresses experienced during welding may lead to premature failure if improper materials are used. For example, the substitution of free-machining steel for low-carbon steel in a part to be welded may lead to failure because the presence of sulfur or selenium in the free-machining steel leads to hot cracking. The specified base metal and filler metal types indicated in welding procedure qualification records must be used, with no substitutions.

Variations between Materials Standards

Variations between materials standards allow them to cover many industrial applications and meet a wide range of quality requirements. Designers select standards that meet the required quality level for the intended service. Using a higher quality than necessary adds to cost. Using a lower quality than necessary may lead to premature failure in service.

For example, ASTM A53 and A106 are specifications for two types of steel piping. ASTM A53 is specified for piping for general use and is not made to any particular steelmaking process. ASTM A106 specifies fine-grain steelmaking practices that result in seamless steels (not shaped by seam welding), less prone to exhibit leakage throughout the pipe wall. These features make ASTM A106 more appropriate for critical service applications where failure from leakage or fracture might lead to injury or significant property damage. See Figure 45-9. The excess cost involved in using A106 for a general-purpose application would be unnecessary since A53 would be acceptable.

STANDARDS COMPARISON					
Standard	**Type**	**Title**	**Most Common**	**Description**	**Uses**
ASTM A53	Specification	"Pipe, Steel, Black and Hot Dipped, Zinc Coated, Welded and Seamless"	Type E Grade B	• Resistance welded • Slightly higher carbon contact than Grade A • Not to fine-grain steelmaking practice	General use
ASTM A106	Specification	"Seamless Carbon Steel Pipe for High-Temperature Service"	Grade B	• Seamless • Balance of strength and weldability • Made to fine-grain steelmaking practice	Critical service

Figure 45-9. *Specification ASTM A53 is a general steel piping specification; ASTM A106 is preferred for critical applications.*

Certification

A *certification* is a notarized statement provided by a supplier verifying that a product meets the specification under which it is sold. Certification types include mill test report, product analysis, certificate of compliance, and filler metal approval.

A *mill test report (MTR),* or certificate of analysis (COA), is certification issued by the primary manufacturer (mill) verifying the chemical analysis and mechanical test properties of stock obtained from a starting ingot or billet of metal. The MTR is reviewed when the order is received. An MTR allows the receiver to check that the materials meet specifications. MTRs do not cost extra when requested in the original purchase order.

Product analysis is supplementary certification that a particular product form is fabricated from a specific billet of metal. Product analysis is performed on items such as tubing or pipe fittings to ensure that substitutions have not been made during processing of the metal. Testing procedures for product analysis are usually destructive, and components that are tested in order to generate a product analysis must be discarded. Product analyses may be included in the certification as a supplemental requirement in ASTM specifications at additional cost. Product analyses are required only at the discretion of the user.

A *certificate of compliance (COC)* is a statement that a material meets the specifications to which it was purchased. A certificate of compliance has little value unless the supplier has an acceptable quality program that verifies that the acceptance steps are valid and have been performed.

Filler metal approval is the process of testing samples of as-received filler metal to certify conformance to a specification. An approved inspector witnesses welding of test plates using electrodes selected at random and mechanical property tests carried out on samples of the test weldments. Approvals are granted for filler metals based on the results of the tests. The approved inspector places the approved product on a qualified products list (QPL).

Retention of filler metal on the approved lists may be subject to annual tests. Filler metal approvals include covered electrodes; submerged arc electrode wire with flux combinations; and flux cored arc welding electrodes with gas combinations.

A certification is a notarized statement that a material meets specifications.

A mill test report is a certification that provides results of chemical and mechanical property tests to indicate the material meets specifications.

MTR Segments

MTR segments indicate the conformance of a material to the standard. These include chemical analysis, mechanical properties, method of manufacture, and special requirements. Each MTR segment is checked against the standard it references to ensure the materials are as specified. Incoming materials are examined to ensure that their markings and dimensions conform to the standard.

When required by codes or standards, it is necessary to verify that received materials conform to the relevant MTR or product analysis. MTRs and product analyses are turned over to the responsible organization after verification or maintained on file. See Figure 45-10. To verify conformance to the MTR or product analysis, follow the procedure:

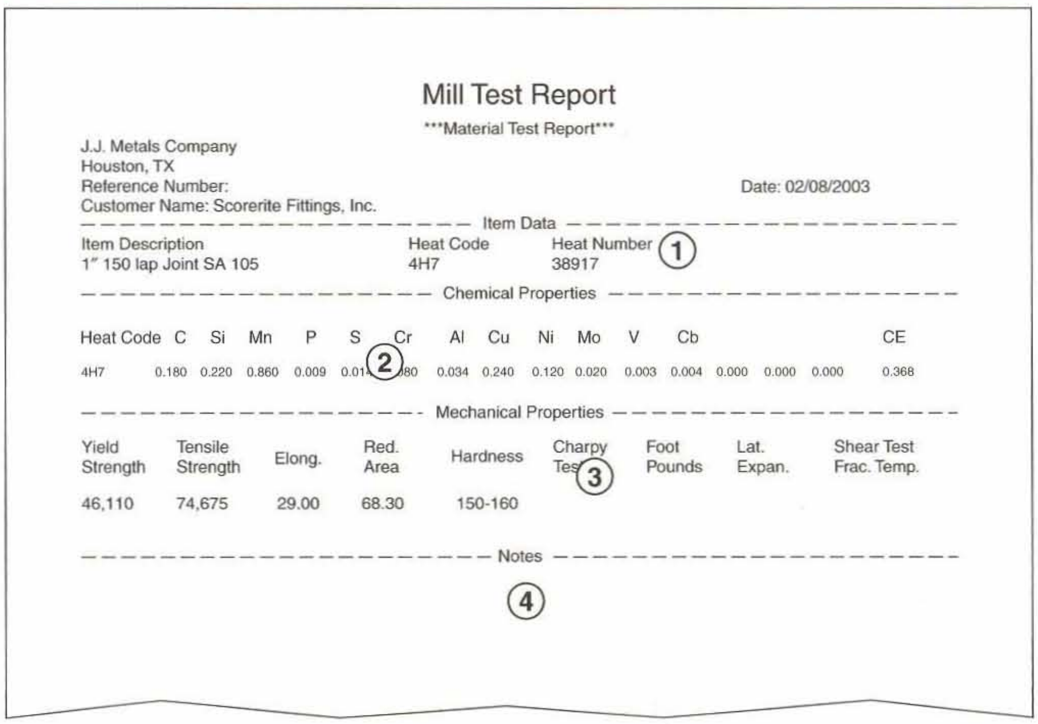
1. Verify that heat number(s) match the heat numbers recorded on the materials.
2. Verify that the chemical compositions are within the limitations indicated by the materials specification.
3. Verify that mechanical properties are within the limitations indicated by the materials specification.
4. Verify that special tests and supplementary requirements conform to the materials specification.

Weld Filler Metals

Weld filler metals are selected in compliance with AWS A5.01, *Filler Metal Procurement Guidelines*. The purchase order must indicate the filler metal specification and embedded designation, and filler metal diameter, length, and quantity. To verify that the filler metal meets the specification, the box and accompanying paperwork are checked. See Figure 45-11. When the box is opened for use, secondary verification is required. Secondary verification consists of supplementary inspection techniques and may include verification of the marking or tab on each piece of filler metal and of the filler metal diameter; and if required for critical applications, may include supplementary chemical analysis.

Figure 45-10. *When required by codes or standards, it is necessary to verify that received materials conform to the relevant MTR or product analysis.*

Mill Test Report Verification
Figure 45-10



Mill Test Report

Material Test Report

J.J. Metals Company
Houston, TX
Reference Number:
Customer Name: Scorerite Fittings, Inc.

Date: 02/08/2003

Item Data

Item Description	Heat Code	Heat Number (1)
1″ 150 lap Joint SA 105	4H7	38917

Chemical Properties (2)

Heat Code	C	Si	Mn	P	S	Cr	Al	Cu	Ni	Mo	V	Cb				CE
4H7	0.180	0.220	0.860	0.009	0.014	[illegible]80	0.034	0.240	0.120	0.020	0.003	0.004	0.000	0.000	0.000	0.368

Mechanical Properties

Yield Strength	Tensile Strength	Elong.	Red. Area	Hardness	Charpy Test (3)	Foot Pounds	Lat. Expan.	Shear Test Frac. Temp.
46,110	74,675	29.00	68.30	150-160				

Notes

(4)

1. Verify MTR heat numbers match heat numbers on material
2. Verify MTR chemical composition conforms to materials specification
3. Verify MTR mechanical properties conform to materials specification
4. Verify MTR special tests and supplementary requirements conform to materials specification

Filler Metals Verification
Figure 45-11

BOX SHOULD SPECIFY:
- AWS classification
- Size - diameter
  - length (for rod)
- Unit package type and weight or quantity

1. Certification — Verify box description matches order exactly. Product must be labeled with manufacturer, heat (or lot) number, address
2. Appearance — Verify description on body or tab conforms to specified AWS identification. Container must be properly sealed
3. Measurement — Verify correct diameter
4. Chemistry — X-ray fluorescence (XRF)*

* if applicable

Figure 45-11. *Secondary verification consists of supplementary inspection techniques and may include verification of the marking or tab on each piece of filler metal, the filler metal diameter, and if required for critical applications, supplementary chemical analysis.*

FABRICATION STANDARDS AND CODES

Fabrication standards and codes are developed from many sources of experience on the reliability of weldment designs for different applications. Fabrication standard development has been driven by the need to define an adequate weld versus the perfect weld for a specific application. Ongoing field experience and research result in continuous refinement of weld quality requirements in industry codes and standards to maintain competitiveness of each segment of business.

Industry-based professional organizations write welding codes and standards. Codes are developed for regulated industries. Standards are developed for less regulated or nonregulated industries. Fabrication standards and codes cover pressure vessels and storage tanks, piping systems, construction, transportation, and heavy machinery. See Appendix.

Pressure Vessels and Storage Tanks

Pressure vessels and storage tanks may contain flammable, toxic, or corrosive liquids and gases. Pressure vessel or storage tank leakage or rupture may lead to significant loss of life and property damage. Pressure vessel and storage tank codes are written for the fabrication of boilers and pressure vessels, nuclear plants, storage tanks, and compressed gas containment systems. Additional in-service inspection and repair codes address repair of boilers, pressure vessels, and storage tanks that have been in service.

Boilers and Pressure Vessels. Boilers and pressure vessels, and items classified as pressure vessels, such as heat exchangers, must meet the requirements of the ASME International Boiler and Pressure Vessel Code in their design and fabrication. Many countries outside the USA and Canada recognize and accept the ASME International Boiler and Pressure Vessel Code, but an equal number of other countries accept only their own national code.

A *Manufacturing Data Report (MDR)* is a legal document signed by the representatives of the manufacturer and the manufacturer's authorized inspection agency. An MDR certifies that all details of design, material, construction, and workmanship conform to the ASME International Boiler and Pressure Vessel Code.

Fabrication standards and codes may be grouped into pressure vessels and storage tanks, piping systems, construction, transportation, and machinery.

Cleaver-Brooks

Pressure vessel fabrication requirements are typically covered under the ASME International Boiler and Pressure Vessel Code.

Many states require that an ASME symbol stamped pressure vessel be registered with the National Board. The pressure vessel is assigned a number, known as the National Board number. The National Board number is shown on the MDR and on the vessel nameplate. The manufacturer sends two copies of the MDR to the National Board, which keeps one on file and sends the other to the state where the pressure vessel will be installed.

A pressure vessel loses its ASME International Boiler and Pressure Vessel Code identity if the MDR is missing and cannot be replaced, or if the nameplate is obliterated. Depending on the jurisdictional authority, such a vessel may need to be replaced. A nameplate must always be clearly visible. With an insulated vessel, a cutout should be made to ensure visibility. Do not paint over a nameplate or otherwise obliterate it.

Information should be restored to a nameplate should it be removed or otherwise deleted. The acid etching technique often reveals information that has been stamped on sheet metal. The acid etching technique consists of grinding, etching, and neutralizing.

Stamped information is revealed using a pencil grinder to very lightly grind the surface of the nameplate to reveal the information.

⚠ WARNING

Acids should be handled in accordance with written procedures to prevent personal injury and equipment damage.

To etch a surface, the vessel is gently swabbed with a suitable acidic solution. After etching, excess acid is neutralized and removed by thoroughly flushing the surface with water. Sufficient water must flow over the surface to remove all traces of acid both from the nameplate and from the surface of the equipment.

By alternating grinding and etching, the nameplate stamping is made readable again. It may be necessary to experiment with the acid etching technique using a piece of aluminum or stainless steel sheet metal containing stamped identifications. The acid etching technique is a viable method of restoring damaged stamped identification tags on motors, tanks, and other items of equipment.

Repairs to boilers and pressure vessels are covered by in-service inspection and repair codes, National Board Inspection Code (NBIC), or API 510, depending on which code is recognized by the state in which the work is done. The purpose of in-service inspection and repair codes is to maintain the integrity of pressure boilers and pressure vessels after they have been placed in service by providing rules and guidelines for inspection after installation, repair, alteration, and rerating. Alteration is any repair that does not restore a mechanical component to its original design. Rerating is revision of the allowable design parameters of a mechanical component from the original design arising from formal study of its current condition. Rerating a pressure vessel results in changes to the design pressure and temperature, which must be recorded on the nameplate.

Any welding done on the pressure boundary of a pressure vessel is subject to the requirements of the applicable in-service inspection and repair code. A pressure boundary is a physical envelope that contains the working pressure of a piece of equipment. Welding in a plug or performing a weld repair to a heat exchanger tube-to-tubesheet joint is classified as a pressure vessel repair

because it involves welding directly on a pressure boundary of the heat exchanger. See Figure 45-12.

Repair organizations that make repairs or alterations will usually have an "R" or "NR" symbol stamp issued by the National Board of Boiler and Pressure Vessel Inspectors.

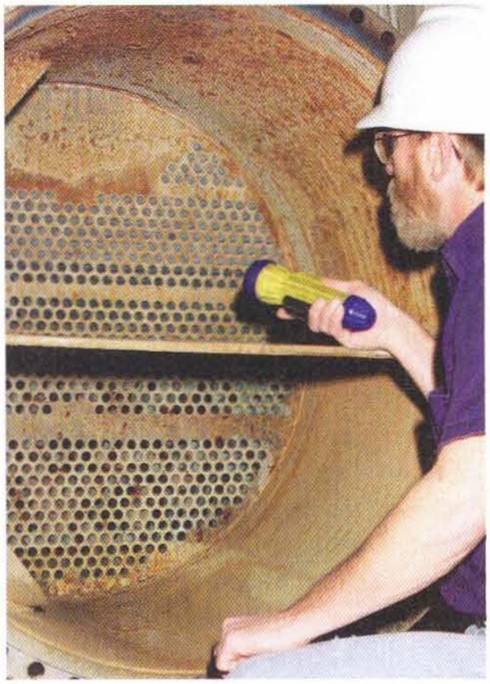


Figure 45-12. *Repairs made to a heat exchanger tube-to-tubesheet joint are classified as pressure vessel repairs because they involve welding directly on a pressure boundary of the heat exchanger.*

Nuclear Plants. Nuclear plant components such as nuclear reactors and materials used in nuclear plants are covered by the provisions of Section III of the ASME International Boiler and Pressure Vessel Code and the Nuclear Regulatory Commission Specification, *Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants.* One exception is nuclear plant components developed for naval ships, which are covered by a code issued by the Department of Defense (DOD) Naval Ship Division Code, *Standard for Welding Reactor Coolant and Associated Systems and Components for Naval Nuclear Power Plants.* The DOD code is similar to Section III of the ASME International Boiler and Pressure Vessel Code. Because of the significant consequences of a failure, nuclear plant codes impose the strictest certification requirements on materials and the traceability of all materials to the point of origin.

Storage Tanks. Storage tanks consist of aboveground storage tanks and elevated storage tanks. Aboveground storage tanks usually contain various fluids, such as petroleum products and chemical solutions, and usually rest on a concrete slab or dunnage. *Dunnage* is a series of steel I-beams parallel to one another. Elevated storage tanks contain water, and may contain petroleum products, and rest on steel towers. All storage tank codes and standards refer to Section IX of the ASME International Boiler and Pressure Vessel Code for welding qualification.

Aboveground storage tanks are designed and fabricated based on the pressure of the tank. API STD 620, *Design and Construction of Large, Welded, Low Pressure Storage Tanks,* covers the design and construction of field-welded pressure tanks used for storage of petroleum intermediates and finished products under a pressure of 15 psig or less (low pressure). API STD 650, *Welded Steel Tanks for Oil Storage,* covers the material, design, fabrication, erection, and testing requirements for vertical, cylindrical welded steel storage tanks that are above ground and not subject to internal pressure.

Fabrication requirements for elevated steel tanks are described in the joint American Waterworks Association (AWWA) and American National Standards Institute (ANSI) ANSI/AWWA D100, *Standard for Welded Steel Tanks for Water Storage.* The joint standard provides a purchase specification to facilitate the manufacture and procurement of welded steel tanks for the storage of water.

Aboveground storage tank repair is covered in in-service inspection and repair code API STD 653, *Tank Inspection, Repair, Alteration, and Reconstruction.* API 653 is based on accumulated knowledge of owners, manufacturers, and repairers of steel storage tanks. API 653 provides guidance in the inspection, repair, alteration, and

reconstruction of steel aboveground storage tanks used in the petroleum and chemical industries. Welding requirements are based on equivalence standard API 650.

Compressed Gas Equipment. The Compressed Gas Association (CGA) develops compressed gas equipment standards. CGA C-3, *Standards for Welding on Thin-Walled, Steel Containers,* covers welding requirements in the manufacture and repair of Department of Transportation (DOT) compressed cylinders.

Piping Systems

Piping systems, like pressure vessels, may transport flammable, toxic, or corrosive liquids. Piping systems are usually more susceptible to catastrophic failure consequences compared with pressure vessels or tanks because piping systems contain many joints and often consist of long exposed runs that may be subject to mechanical abuse. Piping system design, fabrication, and repair are covered by codes that encompass pressure piping, line piping, and water piping.

Pressure Piping. Pressure piping in thermal and nuclear power plants, refineries, and chemical plants is designed and fabricated in accordance with ASME B31, Code for Pressure Piping. Pressure piping is usually medium- to thick-wall (described by schedule) and medium- to large-size (described by diameter). The ASME Code for Pressure Piping is divided into seven Sections applicable to different end-use categories of pressure piping.

Welding procedures and qualifications vary according to the applicable Section of the ASME Code for Pressure Piping. Welding procedures and qualifications are generally in accordance with Section IX of ASME International Boiler and Pressure Vessel Code unless other codes or qualifications are referred to.

Pressure piping repair is covered by in-service inspection and repair code API 570, *Piping Inspection Code: Inspection, Repair, Alteration, and Rerating of In-Service Piping Systems.* API 570 is also applicable to ASME B31.3, *Process Piping,* and other pressure piping code sections. API 570 establishes requirements and guidelines that allow owners and users of piping systems to maintain the safety and integrity of the piping systems that have been placed into service. All repair and alteration welding must be done in accordance with ASME B31.3, or the code to which the piping system was built.

Line Piping (Cross Country Piping). Line piping consists of transmission and distribution piping that transports fuel gases, crude petroleum, and petroleum products. *Transmission piping* is medium- to high-strength steel, relatively thin-wall and large-diameter, and conveys products from locations of production to intermediate facilities. *Distribution piping* is carbon-steel, standard-size pipe of small diameter that conveys products from intermediate facilities to consumers.

Transmission piping welding requires special techniques and procedures and is governed by API 1104. API 1104 applies to arc welding and oxyfuel welding of piping used in the compression, pumping, and transmission of fuel gases, crude petroleum, and petroleum products. API 1104 presents methods for the production of acceptable welds by qualified welders using qualified welding procedures, materials, and equipment. It also contains acceptability standards and standards for repair of weld defects. API 1104 also applies to distribution piping where applicable.

Line piping repair and maintenance are covered in API Recommended Practice 1107. The primary purpose of API Recommended Practice 1107 is safety. It prohibits unsafe practices and warns against practices for which caution is necessary. API Recommended Practice 1107 includes methods for the inspection and repair of welds, and for installing appurtenances on loaded piping systems.

Water Piping. Water piping is made of low-carbon steel. AWWA C206: *Field Welding of Steel Water Pipe,* covers the welding of circumferential joints as well as the fabrication and installation of specials and accessories. The maximum thickness of piping covered by AWWA C206 is 1¼″.

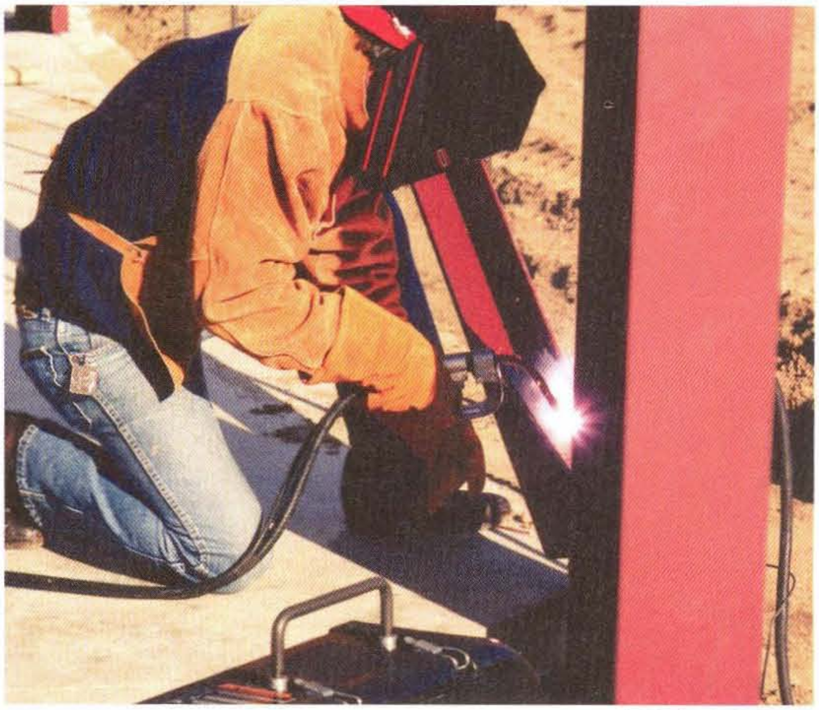
Construction

Construction applications of welding encompass structural steel and aluminum used for buildings and highway bridges; reinforcing steel for concrete; and sheet metal. Welded joint types and configurations in construction applications are critical to the integrity of the component. Catastrophic failure may cause loss of life, injury, and costly related damage.

Structural Steel. Structural steel fabrication practices for constructing buildings and edifices are comprehensively regulated to prevent unsafe conditions during or after construction. Steel buildings welded in most cities in North America are covered by codes and specifications. Many large cities publish their own specific codes, while others follow AWS D1.1, *Structural Welding Code–Steel.* AWS D1.1 covers welding requirements for any type of welded structure made from commonly used carbon and low-alloy structural steels. AWS D1.1 does not apply to base metals less than ⅛″ thick. Additionally, it contains allowable unit stresses, structural details, workmanship standards, inspection procedures, and acceptance criteria. AWS D1.1 contains sections devoted exclusively to buildings (static loading), bridges (dynamic loading), and tubular structures.

Structural Aluminum. Structural aluminum is used for its lightness coupled with its strength and atmospheric corrosion resistance. Welding requirements for structural aluminum are contained in AWS D1.2, *Structural Welding Code–Aluminum.* AWS D1.2 contains general rules for the regulation of welding in aluminum construction plus additional, supplementary rules applicable to statically loaded structures, dynamically loaded structures, and tubular structures.

Sheet Metal. Sheet metal is metal that is ⅛″ thick or less, corresponding to a gauge number of 11 or higher. The higher the number, the thinner the gauge. Under normal manual or semiautomatic welding conditions, sheet metal as thin as .035″ or roughly 20-gauge can be welded. There are two sheet metal welding codes, which apply to structural and nonstructural applications.



The Lincoln Electric Company

AWS D1.1, Structural Welding Code–Steel, *contains sections devoted exclusively to buildings.*

AWS D1.3, *Structural Welding Code–Sheet Steel,* covers requirements for welding sheet steel having a minimum specified yield point no greater than 80 ksi. AWS D1.3 covers sheet steel with or without zinc coating (galvanizing). The welding may involve connections of sheet or strip steel to thicker supporting structural members, in which case provisions of AWS D1.1, *Structural Welding Code–Steel,* also apply.

AWS D9.1, *Sheet Metal Welding Code,* covers nonstructural sheet metal requirements. AWS D9.1 provides requirements for welding carbon steel,

low-alloy steel, austenitic and ferritic stainless steel, aluminum, copper, and nickel alloy sheet steels. AWS D9.1 provides requirements for nonstructural fabrication and erection of sheet metal by welding and braze welding for heating, ventilating, and air conditioning systems; architectural usage; food processing equipment; and similar applications. Where differential air pressures of more than 120″ (30 kPa) of water or structural requirements are involved, other standards are to be used.

Reinforcing Steel. Reinforcing steel is high-carbon steel rod used to reinforce concrete for structural applications and is manufactured to ASTM A615. AWS D1.4, *Structural Welding Code–Reinforcing Steel,* covers requirements for welding reinforcing steel in most reinforced concrete applications. AWS D1.4 contains regulations for welding reinforcing steel, and provides acceptable criteria for such welds.

Highway Bridges. Highway bridge welding is under the jurisdiction of the state or provincial department of transportation, either by reference to, or by direct copy of AWS D1.5, *Bridge Welding Code.* AWS D1.5 is a joint standard of the American Association of State Highway and Transportation Officials (AASHTO) and the AWS. AWS D1.5 covers welding requirements for AASHTO welded highway bridges made from carbon and low-alloy steels. Failure-critical members of a bridge may require special standards of welded workmanship only by organizations having the proper personnel, experience, procedures, knowledge, and equipment. A *failure-critical member* is a tension member or component whose failure would likely result in collapse of the structure.

Many states supplement the AASHTO and AWS requirements with their own additional standards. Some states require welders to be examined yearly and be certified by the state to work on bridges. Some states maintain rosters of certified welders.

Transportation

The transportation industry represents a diverse set of end uses for welded products. Welded joints in transportation equipment are subject to tensile, compressive, torsional, bending, and shear stresses, in addition to fatigue stresses because of loading and motion. Transportation welding is not as regulated as welding in other industry segments, with the exception of certain types of transportation where there is significant opportunity for catastrophe in the event of failure. Transportation welding standards and codes cover automobiles and trucks, railroad cars and locomotives, aircraft and aerospace vehicles, ships and barges, shipping containers, and underwater welding.

Automobiles and Trucks. Automobile and truck welding is usually carried out by resistance welding and robotic arc welding. See Figure 45-13. For high production rates such as automobile and truck subassemblies, multiple spot welding machines are used. Welding specifications for resistance and arc welding are covered in joint standards created by the SAE and the AWS. AWS Recommended Practice D8.7, *Automotive Weld Quality–Resistance Spot Welding,* covers quality requirements for resistance spot welding of common automotive sheet steel systems, excluding high-strength low-alloy steel. AWS D8.8, *Automotive Frames Weld Quality–Arc Welding* defines practical tolerances for good fit-up in order to achieve satisfactory weld quality in automotive structural parts joined by robotic welding. Metal stampings and press-formed parts must be made to produce weld joint fit-up within the allowances of the specification.

Railroad Cars and Locomotives. Repair of railroad cars and locomotives is in accordance with AWS D15.1, *Railroad Welding Specification–Cars and Locomotives.* AWS D15.1 is jointly developed with the Association of American Railroads (AAR). Part I covers specific

requirements for welding in the railroad industry. Part II covers specific requirements for welding on railroad freight cars other than tank cars. Welding on freight cars is performed as required in Part I except as specifically detailed in Part II. The rules for welding on tanks in tank cars are covered by the ASME International Boiler and Pressure Vessel Code. Part III of AWS D15.1 covers specific requirements for welding locomotives with emphasis on the welding of base metals less than ⅛″ thick.

Chrysler Corporation

Figure 45-13. *Automobile and truck welding is usually performed by robotic arc welding.*

Aircraft and Aerospace Vehicles. The United States Department of Defense (DOD) standard, MIL-STD-195, *Qualifications of Aircraft, Missile, and Aerospace Fusion Welders,* establishes the procedure for welders and welding operators engaged in the fabrication of components for aircraft, missiles, and other aerospace equipment by fusion welding processes. The standard is applicable when required in the contracting documents, or when invoked in the absence of a specified welder qualification document. MIL-STD-195 covers many welding processes, metals, and levels of proficiency for testing welders. Qualification to this standard is performed under the supervision of government inspectors.

Ships and Barges. Ship and barge welding requirements are covered by jurisdictions or insurance companies. The American Bureau of Shipping (ABS) issues *Rules for Building and Classing Steel Vessels,* one section of which covers welding requirements. These rules are required for ships registered and insured in the United States. ABS also approves specific welding consumables in *Approved Welding: Electrodes, Wire-Flux, and Wire-Gas Combinations.* Many insurance companies also publish specifications that cover welding. All United States federal government vessels are covered by codes issued by the U.S. Coast Guard or the Navships Division, Department of Defense. Their requirements are covered, respectively, in *Marine Engineering Regulations,* subchapter F, Part 57, *Welding and Brazing;* and *Fabrication, Welding, and Inspection of Ships Hulls,* Navships 0900-000-1000. AWS D3.5, *Guide for Steel Hull Welding,* provides information on practical methods to weld steel hulls for ships, barges, mobile offshore drilling units, and other marine vessels. The guide provides information on weldability of steel plates, shapes, castings, and forgings. Hull construction is discussed in terms of preparation of materials, erection and fitting, and distortion control.

AWS D3.7, *Guide for Aluminum Hull Welding,* provides information on welding aluminum hulls and related ship structures. It applies chiefly to the welding of aluminum hulls that are over 30′ in length and made of sheet and plate $3/16''$ thick or more. The distinction is made because there are different requirements for welding thin (less than $3/16''$) and thick (greater than ¼″) aluminum.

Shipping Containers. Shipping containers are used to transport gas under high pressure and for tanks carrying liquid petroleum and similar products. The fabrication of shipping containers is under strict regulation because of the serious consequences of failure. The United States Government publishes the Code of Federal Regulations (CFR), which includes standards that govern the fabrication of shipping containers. The applicable standards are 49 CFR 178.345,

General Design and Construction Requirements; and 49 CFR 178.337–Specification MC 331, *Cargo Tank Motor Vehicles.*

Underwater Welding. Underwater welding can be performed in wet or dry environments. Wet underwater welding (welding in the wet) is done under fully immersed conditions and produces relatively poor quality welds that are intended for temporary applications. Dry underwater welding (welding in the dry) is achieved by creating a local underwater environment free of water in which to perform welding. High quality welds are possible with dry underwater welding. See Figure 45-14.

AWS D3.6, *Specification for Underwater Welding,* covers the requirements for wet and dry underwater welding. Weld quality categories (classes) are linked to weld quality requirements. Class A is for welds comparable in quality to above-water welding. Class B is for less critical applications. Class C is for applications where load bearing is not a primary consideration. Class O is for when it is necessary to meet the requirements of another designated code or specification.

Welders who want to advance in the underwater welding field must currently be or become trained, certified divers.

Heavy Machinery

Heavy machinery is subject to rotation, vibration, sudden (impact) or slow application of large loads, and load reversals (fatigue). There are no codes that cover welding of heavy machinery. However, AWS publishes standards that cover the welding of overhead cranes and material handling equipment, machine tools, earthmoving and construction equipment, and rotating equipment. AWS standards for heavy machinery welding indicate minimum requirements for welded fabrication of the types of equipment covered.

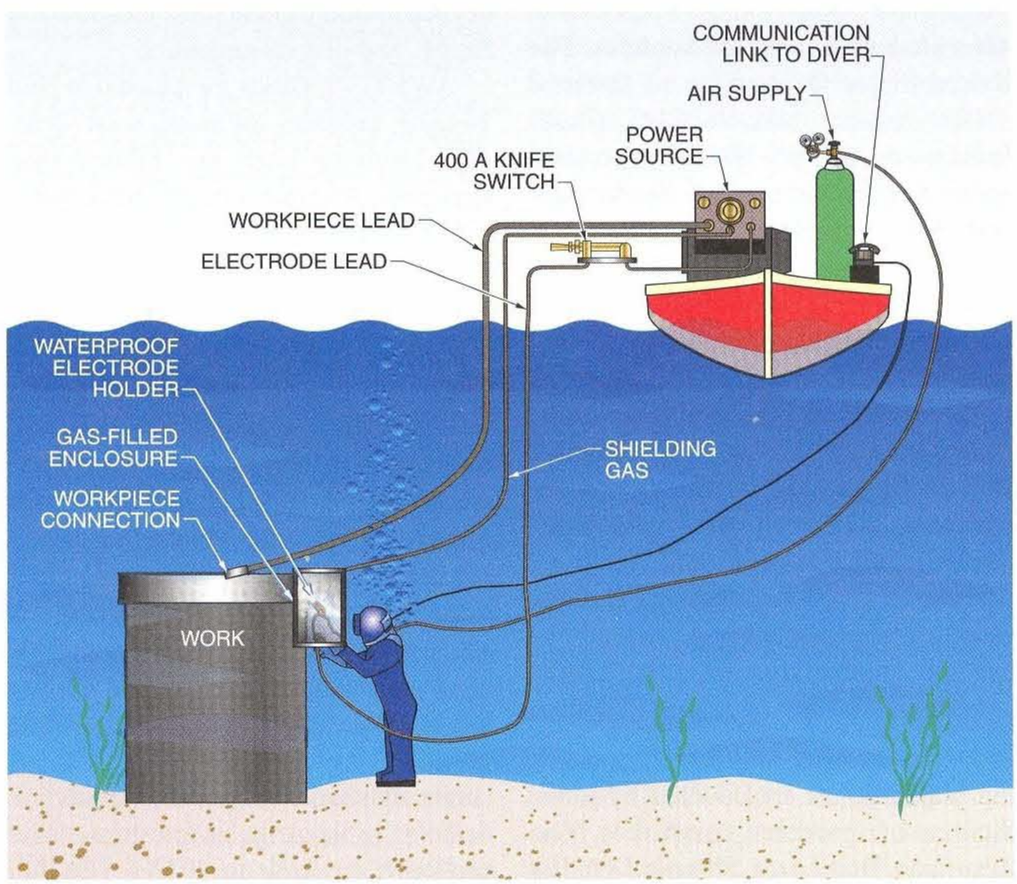


Figure 45-14. *High quality welds are possible with dry underwater welding.*

Overhead Cranes and Material Handling Equipment. Overhead cranes and material handling equipment welding uses plate girders and other welded plate structures rather than rolled beams normally used in fabricating steel for bridges and buildings. Overhead cranes and material handling equipment are subject to vibration and moving loads. Service conditions and the associated fully reversible loading to which cranes and equipment are exposed results in a large number of load cycles in a relatively short period and local bending stresses of significant levels. AWS D14.1, *Specification for Welding Industrial Mill Cranes and Other Material Handling Equipment,* covers base metals, filler metals, joint designs, and qualification of welders and welding operators who work on overhead cranes and material handling equipment.

Machine Tools. Machine tool welding is covered in AWS D14.2, *Specification for Metal Cutting Machine Tool Weldments,* which details requirements for the manufacture and repair of machine tool components, including structures and castings. Filler metals are recommended for the applicable base metals and include carbon steels, low-alloy steels, and austenitic stainless steels. Joint designs and unit stresses are provided for fillet and groove welds.

Earthmoving and Construction Equipment. Earthmoving and construction equipment welding is covered in AWS D14.3, *Specification for Welding Earthmoving and Construction Equipment,* which applies to all structural welds used in such equipment. AWS D14.3 reflects welding practices used by manufacturers within the industry and incorporates various methods that have been proven successful by individual manufacturers. No restrictions are placed on the use of any welding process or procedure, provided the weld produced meets the qualification requirements of the specification.

Rotating Equipment. Rotating equipment welding, such as on fans, pumps, and compressors, is covered in AWS D14.6, *Specification for Welding of Rotating Elements of Equipment.* The standard covers base metals; welding processes; filler metals; welding procedure and performance qualification; fabrication requirements; inspection and quality control; and modification and repair.

POINTS TO REMEMBER

1. Materials standards and codes are developed by consensus (agreement) among parties representing producers, end users, and general interest groups.
2. Codes are mandatory standards that have been adopted by a jurisdictional body.
3. Standards types include specifications, recommended practices, and codes.
4. Two types of activity in standards creation are new standards development and existing standards revision.
5. Various industry groups write materials standards and codes, but the largest set of standards is produced by ASTM International (ASTM).
6. Standards pertaining to welding are published by AWS and cover welding processes, filler metals, and health.
7. Purchase orders for materials refer to applicable materials standards and codes.
8. A certification is a notarized statement that a material meets specifications.
9. A mill test report is a certification that provides results of chemical and mechanical property tests to indicate the material meets specifications.
10. Fabrication standards and codes may be grouped into pressure vessels and storage tanks, piping systems, construction, transportation, and machinery.

QUESTIONS FOR STUDY AND DISCUSSION

1. What types of groups must interact in order to create an effective industry standard?
2. What is the difference between a specification and a recommended practice?
3. What is the difference between a standard and a code?
4. What organization is the largest source of materials standards?
5. Explain each of the components for an ASTM material designated as A193-97 grade B7 (i.e., A, 193, 97, and grade B7).
6. Why is it necessary to indicate not only the ASTM standard number for a material but also the embedded grade, type, or class?
7. What are the AWS prefixes for rod, electrode, rod or wire, and electrode rod or wire?
8. How is an ASME material identified compared with an equivalent ASTM material?
9. How is an ASME filler metal identified compared with an equivalent AWS material?
10. What is the difference between a certification and a mill test report?
11. Does a certificate of compliance provide numerical information on analysis or properties of a material?
12. What type of information is contained in a manufacturing data report for a pressure vessel?

Appendix

STANDARD WELDING TERMINOLOGY	
Common (Field) Terminology	**Standard AWS Terminology**
Welding Processes	
Gas welding	Oxyfuel gas welding (OFW)
Stick welding	Shielded metal arc welding (SMAW)
TIG welding	Gas tungsten arc welding (GTAW)
MIG welding	Gas metal arc welding (GMAW)
Short arc	Short circuiting transfer
Spray arc	Spray transfer
Welding Terms	
Arc gap, electrode gap	Arc length
Arc gas	Orifice gas
Back-up bar	Backing or backing bar
Blowhole, gas pocket, or wormhole	Porosity
Burn-through	Melt-through
Cap pass	Cover pass
Cold lap	Incomplete fusion
Contact tube	Contact tip
Cup or gas cup	Gas nozzle
Downhand	Flat position welding
Edge-flange weld	Edge weld in a flanged butt joint
Fill pass or filler pass	Intermediate weld pass
Filler bead	Intermediate weld bead
Flame cutting or gas cutting	Oxygen cutting
Ground clamp, Welding ground, or work connection	Workpiece connection
Ground lead or work lead	Workpiece lead
Included angle	Groove angle
Joint opening	Root opening
Land	Root face
Machine welding	Mechanized welding
Metallizing	Thermal spraying
Molten weld pool	Weld pool
Nondestructive evaluation or Nondestructive testing	Nondestructive examination
Parent metal	Base metal
Postweld heat treatment	Postheating
Puddle or weld puddle	Weld pool
Root gap	Root opening
Shoulder	Root face
Shrinkage stress	Residual stress
Skip weld	Intermittent weld
Silver soldering	Brazing
Soft solder	Solder
Hard solder	Brazing filler metal
Suck-back	Underfill
Vertical down	Downhill
Vertical up	Uphill
Wash pass	Cover pass

MASTER CHART OF WELDING AND JOINING PROCESSES

WELDING AND JOINING PROCESSES

ARC WELDING (AW)

arc stud welding	SW
atomic hydrogen welding	AHW
bare metal arc welding	BMAW
carbon arc welding	CAW
gas carbon arc welding	CAW-G
shielded carbon arc welding	CAW-S
twin carbon arc welding	CAW-T
electrogas welding	EGW
flux cored arc welding	FCAW
gas-shielded flux cored arc welding	FCAW-G
self-shielded flux cored arc welding	FCAW-S
gas metal arc welding	GMAW
pulsed gas metal arc welding	GMAW-P
short circuit gas metal arc welding	GMAW-S
gas tungsten arc welding	GTAW
pulsed gas tungsten arc welding	GTAW-P
magnetically impelled arc welding	MIAW
plasma arc welding	PAW
shielded metal arc welding	SMAW
submerged arc welding	SAW
series submerged arc welding	SAW-S

RESISTANCE WELDING (RW)

flash welding	FW
pressure-controlled resistance welding	RW-PC
projection welding	PW
resistance seam welding	RSEW
high-frequency seam welding	RSEW-HF
induction seam welding	RSEW-I
mash seam welding	RSEW-MS
resistance spot welding	RSW
upset welding	UW
high-frequency	UW-HF
induction	UW-I

SOLDERING (S)

dip soldering	DS
furnace soldering	FS
induction soldering	IS
infrared soldering	IRS
iron soldering	INS
resistance soldering	RS
torch soldering	TS
ultrasonic soldering	USS
pressure gas soldering	WS

SOLID STATE WELDING (SSW)

coextrusion welding	CEW
cold welding	CW
diffusion welding	DFW
hot isostatic pressure welding	HIPW
explosion welding	EXW
forge welding	FOW
friction welding	FRW
direct drive friction welding	FRW-DD
friction stir welding	FSW
inertia friction welding	FRW-I
hot pressure welding	HPW
roll welding	ROW
ultrasonic welding	USW

OXYFUEL GAS WELDING (OFW)

air acetylene welding	AAW
oxyacetylene welding	OAW
oxyhydrogen welding	OHW
pressure gas welding	PGW

BRAZING (B)

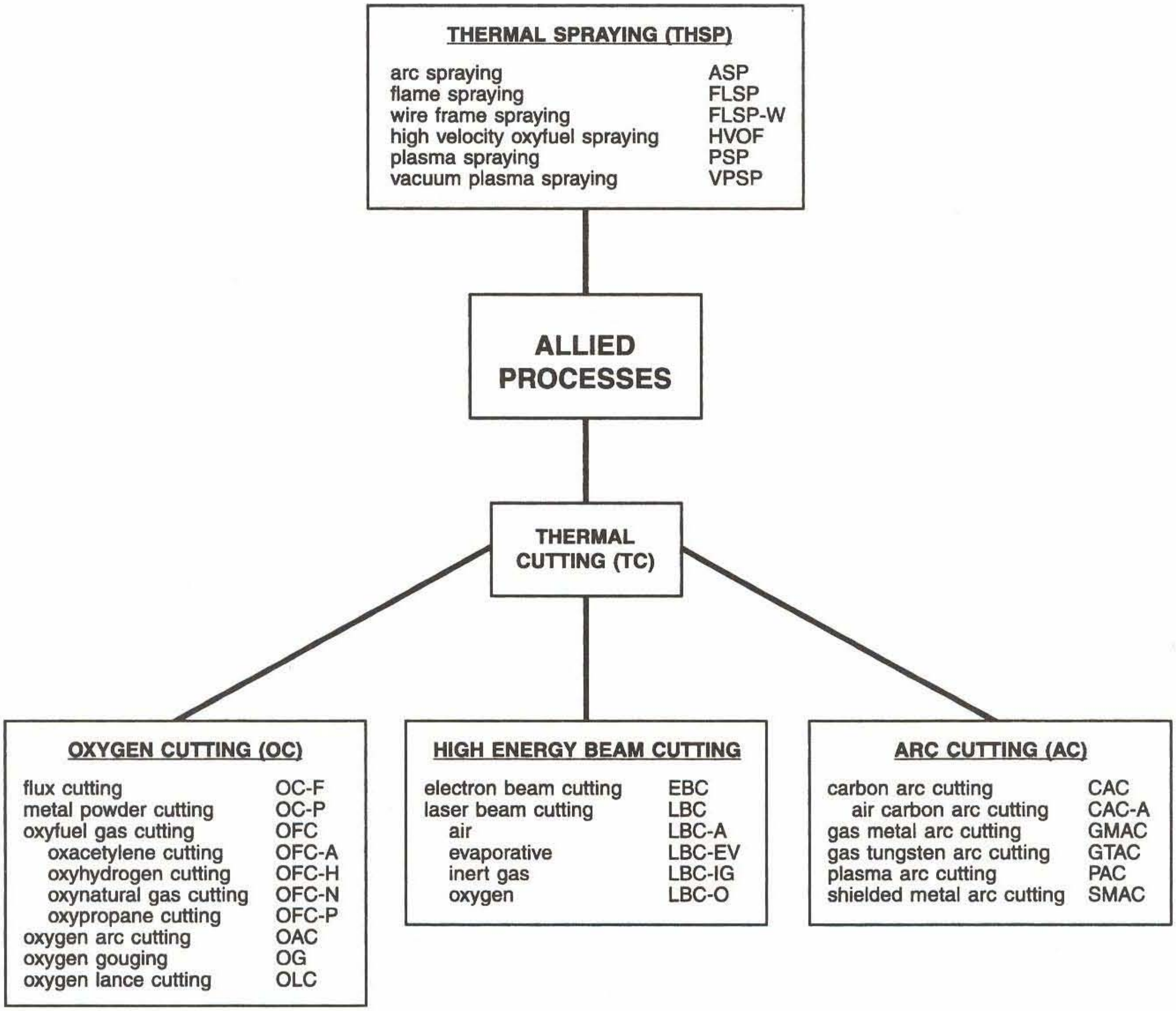
block brazing	BB
diffusion brazing	DFB
dip brazing	DB
exothermic brazing	EXB
furnace brazing	FB
induction brazing	IB
infrared brazing	IRB
resistance brazing	RB
torch brazing	TB
twin carbon arc brazing	TCAB

OTHER WELDING AND JOINING

adhesive bonding	AB
braze welding	BW
arc braze welding	ABW
carbon arc braze welding	CABW
electron beam braze welding	EBBW
exothermic braze welding	EXBW
flow brazing	FLB
flow welding	FLOW
laser beam braze welding	LBBW
electron beam welding	EBW
high vacuum	EBW-HV
medium vacuum	EBW-MV
nonvacuum	EBW-NW
electroslag welding	ESW
consumable guide electroslag welding	ESW-CG
induction welding	IW
laser beam welding	LBW
percussion welding	PEW
thermite welding	TW

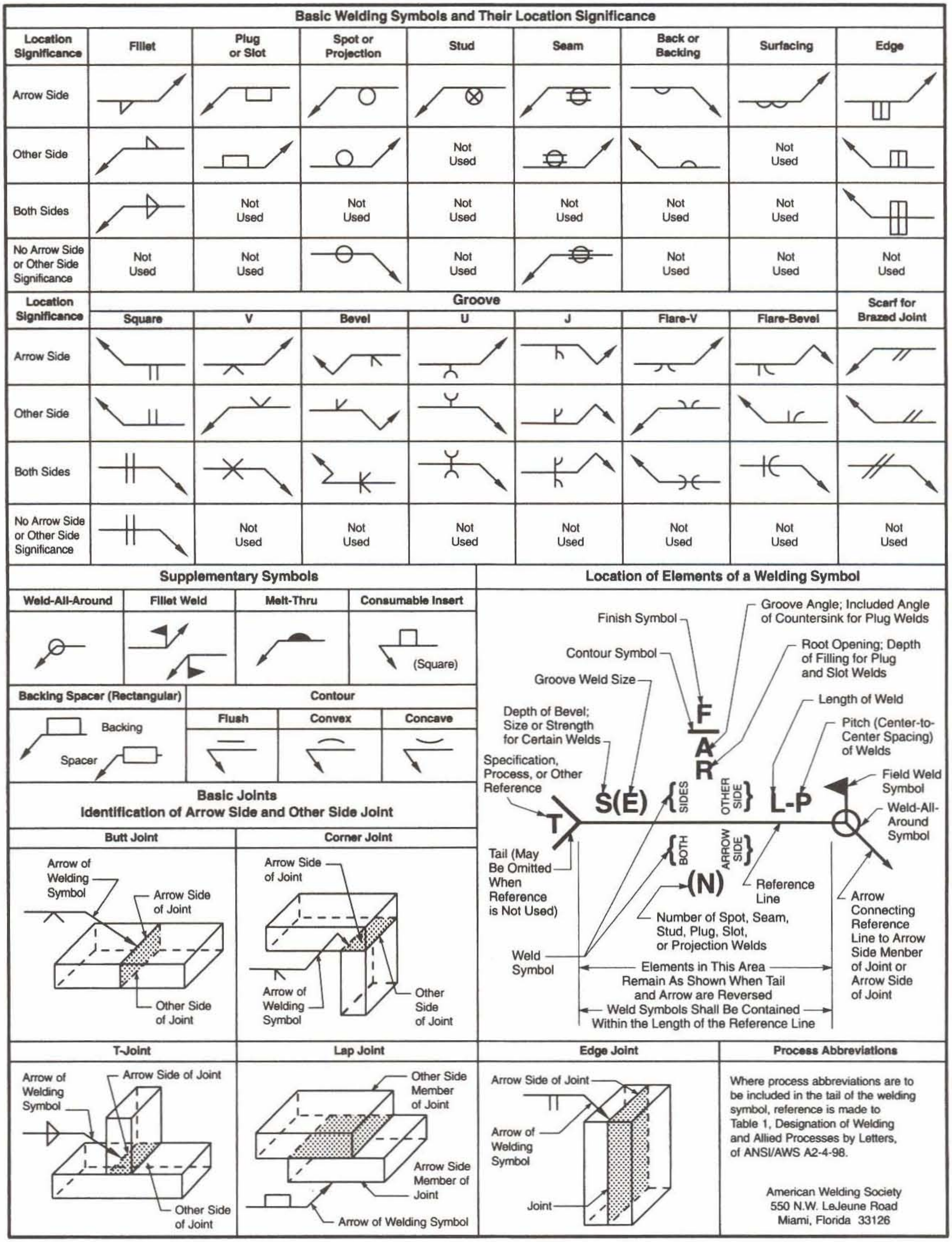
American Welding Society

MASTER CHART OF ALLIED PROCESSES

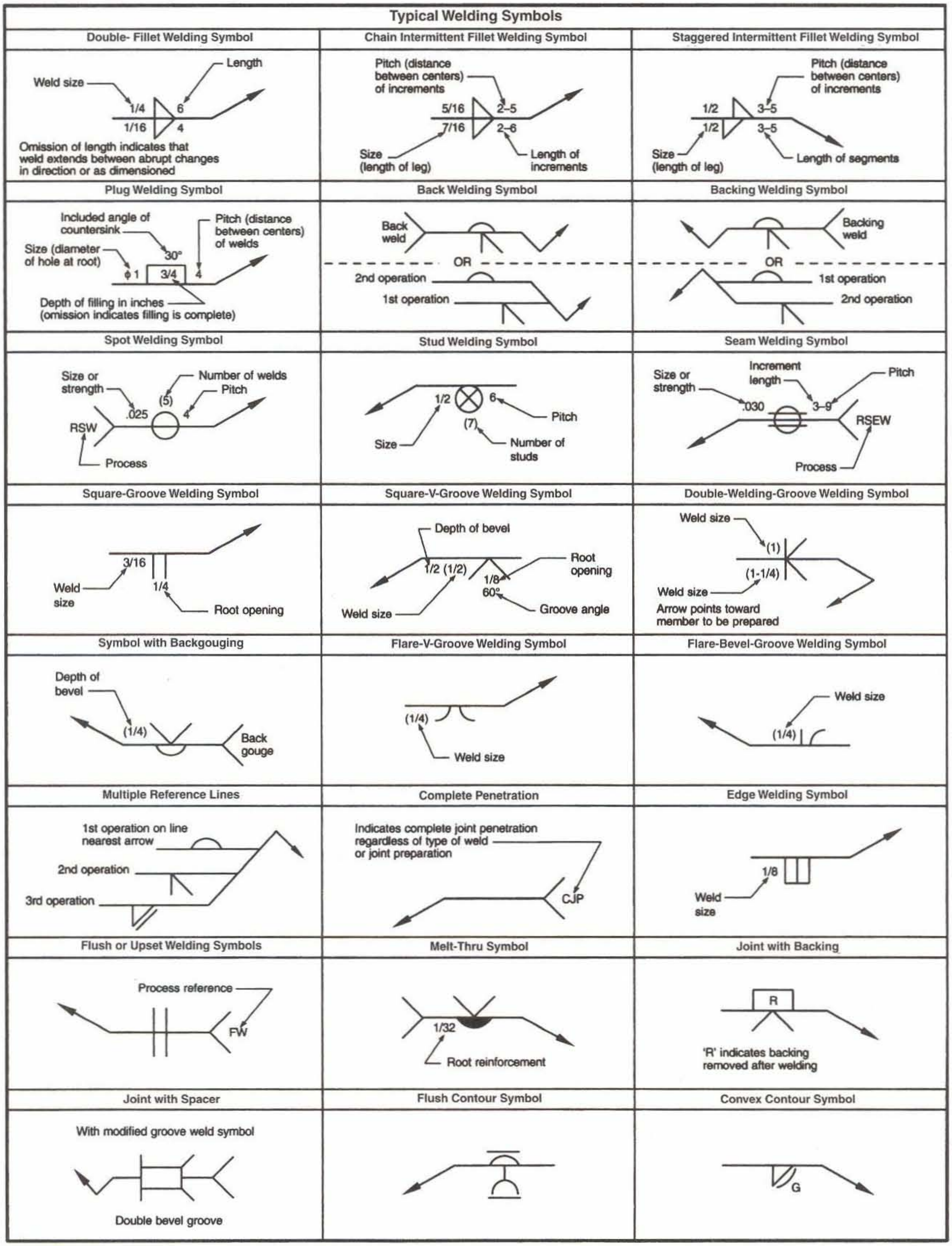


American Welding Society

AMERICAN WELDING SOCIETY
Welding Symbol Chart



AMERICAN WELDING SOCIETY
Welding Symbol Chart



*It should be understood that these charts are intended only as shop aids. The only complete and official presentation of the standard welding symbols is in A2.4.

MISCELLANEOUS WELD DEFECTS	
Problem	**Remedy**
Undercutting	
Improper Electrode Manipulation	Pause at each side of the weld bead when using a weaving technique; use proper electrode angles
Welding current set too high	Reduce welding current (use proper current for electrode size and welding position)
Arc length too long	Reduce arc length
Travel speed too fast	Reduce travel speed
Arc blow	Reduce effects of arc blow; reset workpiece connections
Overlap	
Travel speed too slow	Increase travel speed
Incorrect electrode angle	Use proper electrode angle
Too large electrode	Use smaller electrode
Spatter	
Arc blow	Reduce effects of arc blow; reset workpiece connections
Welding current set too high	Reduce welding current (use proper current for electrode size and welding position)
Arc length too long	Reduce arc length
Wet, dirty, or damaged electrode	Properly maintain and store electrodes

POTENTIAL EFFECTS OF OXYGEN-DEFICIENT ATMOSPHERES*	
Oxygen Content†	**Effects and Symptoms‡**
19.5	Minimum permissible oxygen level
15–19.5	Decreased ability to work strenuously. May impair condition and induce early symptoms in persons with coronary, pulmonary, or circulatory problems
12–14	Respiration exertion and pulse increases. Impaired coordination, perception, and judgment
10–11	Respiration further increases in rate and depth, poor judgment, lips turn blue
8–9	Mental failure, fainting, unconsciousness, ashen face, blue lips, nausea, and vomiting
6–7	8 min, 100% fatal; 6 min, 50% fatal; 4 min–5 min, recovery with treatment
4–5	Coma in 40 sec, convulsions, respiration ceases, death

* values are approximate and vary with state of health and physical activities
† % by volume
‡ at atmospheric pressure

WELD DEFECT EVALUATION GUIDE...

Types of Defect	Pressure Vessels (per ASME, Section VIII)		Chemical Plant and Petroleum Refinery Piping (per ANSI Piping Code)	
	100% X-Ray*	Spot X-Ray*	100% X-Ray*	Random X-Ray*
Cracks	None Allowed	None Allowed	None Allowed	None Allowed
Incomplete Penetration at root pass	None Allowed	None Allowed	None Allowed	• Maximum of 1/32″ or 20% of wall thickness, whichever is smaller • Maximum length of 1½″ in 6″ weld • None allowed for longitudinal welds
Incomplete Penetration due to high-low fit-up	None Allowed	None Allowed	None Allowed	• Maximum of 1/32″ or 20% of wall thickness, whichever is smaller • Maximum length of 1½″ in 6″ weld • None allowed for longitudinal welds
Lack of Fusion at root pass	None Allowed	None Allowed	None Allowed	None Allowed
Lack of Fusion at groove face or between beads, "cold lap"	None Allowed	None Allowed	None Allowed	None Allowed
Melt-through	Not Covered	Not Covered	Not Covered	Not Covered
Internal Concavity	Shall not reduce weld thickness to less than thinner material. Contour of concavity shall be smooth	Shall not reduce weld thickness to less than thinner material. Contour of concavity shall be smooth	Shall not reduce weld thickness to less than thinner material	Shall not reduce weld thickness to less than thinner material
Undercut at root pas or cover pass	1/32″ or 10%t†, whichever is less	1/32″ or 10%t†, whichever is less	• Maximum depth of 1/32″ or 25% of wall thickness, whichever is smaller • None allowed for longitudinal butt joints	• Maximum depth of 1/32″ or 25% of wall thick-ness, whichever is smaller • None allowed for longitudinal butt joints
Slag Inclusions elongated, except as noted	**Material Thickness** — **Maximum Slag Length** less than or equal to ¾″ — ¼″ ¾″ to 2¼″ — 1/3t† greater than 2¼″ — ¾″	• Maximum length of 2/3T‡ where T‡ is thickness of material, with ¾″ Maximum • Maximum total length of T‡ in 6″ weld length	• Maximum length of 1/3T‡ and width lesser of 3/32″ or 1/3T‡ • Maximum total length of T‡ in 12T‡ of weld	• Maximum length of 2T‡ and width lesser of 1/8″ or 1/2T‡ • Maximum total length of 4T‡ in 6″ weld
Porosity	• Maximum individual size shall be smaller of 1/4t† or 5/32″ (or 1/3t† or 1/4″ if 1″ separation) • The length of an acceptable cluster shall not exceed the lesser of 1″ or 2t†	Any size or amount is acceptable	• Maximum 1/3T‡ or 1/8″, whichever is less, greatest dimension of individual pore • Maximum total area 3X area of maximum single allowable pore for any square inch of weld (For piping or elongated porosity use slag inclusion criteria)	• Maximum 1/2T‡ or 1/8″, whichever is less, greatest dimension of individual pore • Maximum total area 3X area of maximum single allowable pore for any square inch of weld
Excess Weld Reinforcement	**Material Thickness** — **Maximum Height** 3/16″ to less than 1″ — 3/32″ 1″ to less than 2″ — 1/8″ 2″ to less than 3″ — 5/32″ 3″ to less than 4″ — 7/32″	**Material Thickness** — **Maximum Slag Length** 3/16″ to less than 1″ — 3/32″ 1″ to less than 2″ — 1/8″ 2″ to less than 3″ — 5/32″ 3″ to less than 4″ — 7/32″	**Thinner Mat'l Thickness. (T‡)** — **Maximum Height** less than or equal to ¼″ — 1/16″ greater than ¼″ to ½″ — 1/8″ greater than ½″ to 1″ — 5/32″ greater than 1″ — 3/16″	**Thinner Mat'l Thickness (T‡)** — **Maximum Height** less than or equal to ¼″ — 1/16″ greater than ¼″ to ½″ — 1/8″ greater than ½″ to ½″ — 5/32″ greater than 1″ — 3/16″
Excessive Root Penetration	Same as Excess Weld Reinforcement	Same as Excess Weld Reinforcement	Same as Excess Weld Reinforcement	Same as Excess Weld Reinforcement
Misalignment	**Material§ Thickness** — **Long# Maximum** — **Circum.** Maximum** less than equal to ½″ — 1/4t† — 1/4t† greater than ½″ to ¾″ — 1/8″ — 1/4t† greater than ¾″ to 1½″ — 1/8″ — 3/16″ greater than 1½″ to 2″ — 1/8″ — 1/8t† greater than 2″ lesser of: — 1/16t† or 3/8″ — 1/8t† or ¾″	**Material§ Thickness** — **Long# Maximum** — **Circum.** Maximum** less than or equal to ½″ — 1/4t† — 1/4t† greater than ½″ to ¾″ — 1/8″ — 1/4t† greater than ¾″ to 1½″ — 1/8″ — 3/16″ greater than 1½″ to 2″ — 1/8″ — 1/8t† greater than 2″ lesser of: — 1/16t† or 3/8″ — 1/8t† or ¾″	Inside diameters of components at ends to be joined must be aligned within engineering design and welding procedure. If the external surfaces of the two components are not aligned, the weld shall be tapered between the two surfaces	Inside diameters of components at ends to be joined must be aligned within engineering design and welding procedure. If the external surfaces of the two components are not aligned, the weld shall be tapered between the two surfaces
Accumulation of Discontinuities	Not Covered	Not Covered	Not Covered	Not Covered
General	No coarse ripples, grooves, overlaps, abrupt ridges or valleys	No coarse ripples, grooves, overlaps abrupt ridges or valleys	Longitudinal butt welds same as 100% X-Ray, except as noted	

* 100% X-Ray, Random X-Ray, and Spot X-Ray are quality level designations used by the ASME pressure vessel and ANSI piping codes and are also used when other NDE methods of evaluation are used
† t = weld thickness
‡ T = thinner material thickness
§ w = weld width
¶ see UHT-20 for special heat-treated ferritic steels
\# joint category A
** joint categories B, C, and D

...WELD DEFECT EVALUATION GUIDE

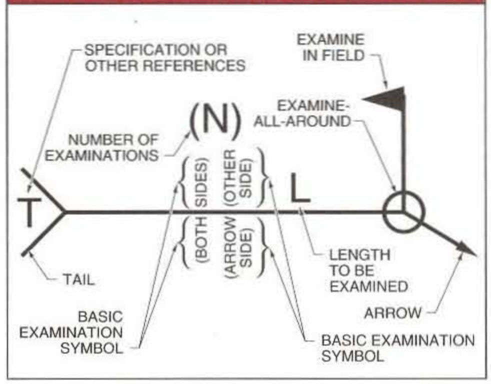
Types of Defect	Pipelines (per API Std. 1104)	Storage Tanks (per API Std. 650)	Power Boilers (per ASME Section 1)
Cracks	None allowed (except shallow crater cracks in the cover pass with maximum length of 5/32″)	None Allowed	None Allowed
Incomplete Penetration at root pass	• Maximum of 1″ in length in 12″ of weld, or 8% of weld length if less than 12″ • Maximum individual length of 1″	None Allowed	None Allowed
Incomplete Penetration due to high-low fit-up	• Maximum individual length of 2″ • Maximum accumulated length of 3″ in 12″ of continuous weld	None Allowed	None Allowed
Lack of Fusion at root pass	• Maximum of 1″ in length in 12″ of weld, or 8% of weld length if less than 12″ • Maximum individual length of 1″	None Allowed	None Allowed
Lack of Fusionat sidewall or between beads, "cold lap"	• Maximum individual length of 2″ • Maximum accumulated length of 2″ in 12″ of continuous weld	None Allowed	None Allowed
Melt-through	**Pipe Diameter** / **Maximum Defect** / **Maximum Total** less than 2¾″ OD / ¼″ / 1″ greater than or equal to 2¾″ OD / ¼″ / ½″ in 2″	Not Covered	Not Covered
Internal Concavity	If density of radiographic image of internal concavity is less than base metal, any length is allowable. If more dense, then see burn-through above	Shall not reduce weld thickness to less than thinner material. Contour of concavity shall be smooth	Not Covered
Undercut at root pass or cover pass	• Maximum depth 1/32″ or 12½% wall thickness, whichever is smaller. • Maximum 2″ length or ⅙ wall thickness, whichever is less, for depth of 1/64″ to 1/32″ or 6% to 12½% of wall thickness, whichever is less	• For horizontal butt joints: maximum depth 1/32″ • For vertical butt joints: maximum depth 1/64″	1/32″ or 10% t†, whichever is less
Slag Inclusions elongated, except as noted	• Maximum length is 2″ and width 1/16″ • Maximum total length 2″ in 12″ of weld. Parallel slag lines are considered separate if width of either exceeds 1/32″. Isolated Slag Inclusions: • Maximum width ⅛″ and ½″ length in 12″ of weld. • No more than 4 isolated inclusions of ⅛″ maximum width.	**Material Thickness** / **Maximum Slag Length** less than or equal to ¾″ / ¼″ ¾″ to 2¼″ / ⅓t† greater than 2¼″ / ¾″ Maximum length of t† in 12t† length	**Material Thickness** / **Maximum Slag Length** less than or equal to ¾″ / ¼″ ¾″ to 2¼″ / ⅓t† greater than 2¼″ / ¾″ Maximum total length of t† in 12t† length
Porosity	Spherical: Maximum dimension ⅛″ or 25% of wall thickness, whichever is less Cluster: Maximum area of ½″ diameter with maximum individual pore dimension of 1/16″. Maximum ½″ length in 12″ weld Hollow Bead: Maximum length ½″. Maximum 2″ length in 12″ weld with individual discontinuities exceeding ¼″ in length separated by at least 2″	• For aligned rounded indications, the summation of diameters less than t in 12t† length • Maximum individual size shall be the smaller of ¼t† or 5/32″ ; or ⅓t† or ¼ if 1″ separation • The length of an acceptable cluster shall not exceed the lesser of 1″ or 2t†	• For aligned rounded indications, the summation of diameters less than t in 12t† length • Maximum individual size shall be the smaller of ¼t† or 5/32″ ; or ⅓t† or ¼″ if 1″ separation • The length of an acceptable cluster shall not exceed the lesser of 1″ or 2t†
Excess Weld Reinforcement	Maximum height of 1/16″	**Material Thickness** / **Vertical Joint Maximum** / **Horizontal Joint Maximum** less than or equal to ½″ / 3/32″ / ⅛″ greater than ½″ to 1″ / ⅛″ / 3/16″ greater than 1″ / 3/16″ / ¼″	**Material Thickness** / **Pipe/Tube Maximum** / **Other Weld Maximum** greater than 3/16″ to ½″ / 5/32″ / 3/32″ greater than ½″ to 1″ / 3/16″ / 3/32″ greater than 1″ to 2″ / ¼″ / ⅛″ greater than 2″ to 3″ / ¼″or ⅛w§ / 5/32″ greater than 3″ to 4″ / ¼″or ⅛w§ / 7/32″
Excessive Root Penetration	Not Covered	Same as Excess Weld Reinforcement	Same as Excess Weld Reinforcement
Misalignment	Maximum 1/16″ Any greater offset, provided it is caused by dimensional variations, shall be equally distributed around the circumference of the pipe	Vertical misalignment less than or equal to 10%t† or 1/16″, whichever is larger Horizontal misalignment less than or equal to 20%t† of upper plate, with ⅛″ maximum	**Material Thickness** / **Long Maximum** / **Circum. Maximum** less than or equal to ½″ / ¼t† / ¼t† greater than ½″ to ¾″ / ⅛″ / ¼t† greater than ¾″ to 1½″ / ⅛″ / 3/16″ greater than 1½″ to 2 / ⅛″ / ⅛t† 2″ lesser of: / 1/16t† or ⅜″ / ⅛t† or ¾″
Accumulation of Discontinuities	Maximum of 2″ in any 12″ or 8% of weld length excluding high-low condition	Not Covered	Not Covered
General	Rights of Rejection—"Since NDE methods give limited indications, the Company may reject welds which appear to meet these standards of acceptability, if in its opinion the depth of the defect may be detrimental to the strength of weld."		No ripples, grooves, abrupt ridges, and valleys to avoid stress risers

* 100% X-Ray, Random X-Ray, and Spot X-Ray are quality level designations used by the ASME pressure vessel and ANSI piping codes and are also used when other NDE methods of evaluation are used
† t = weld thickness
‡ T = thinner material thickness
§ w = weld width
‖ see UHT-20 for special heat-treated ferritic steels
joint category A
** joint categories B, C, and D

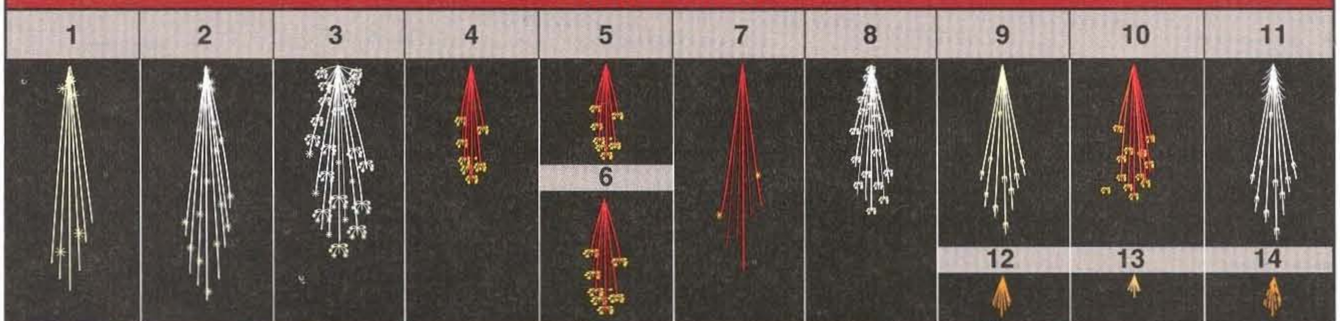
NONDESTRUCTIVE EXAMINATION	
Method	**Letter Designation**
Acoustic emission	AET
Electromagnetic	ET
Leak	LT
Magnetic particle	MT
Neutron radiographic	NRT
Penetrant*	PT
Proof*	PRT
Radiographic*	RT
Ultrasonic*	UT
Visual*	VT

*methods used for testing pipe welds

NDE EXAMINATION SYMBOL



SPARK CHART



Metal	Stream Volume	Relative Length*	Color of Stream	Color of Bursts	Quantity of Bursts	Nature of Bursts
1. Wrought Iron	Large	65	Straw	White	Very few	Forked
2. Machine Steel (AISI 1020)	Large	70	White	White	Few	Forked
3. Carbon Tool Steel	Moderately large	55	White	White	Very many	Fine, repeating
4. Gray Cast Iron	Small	25	Red	Straw	Many	Fine, repeating
5. White Cast Iron	Very small	20	Red	Straw	Few	Fine, repeating
6. Annealed Mall. Iron	Moderate	30	Red	Straw	Many	Fine, repeating
7. High-Speed Steel (18-4-1)	Small	60	Red	Straw	Extremely few	Forked
8. Austenitic Manganese Steel	Moderately large	45	White	White	Many	Fine, repeating
9. Stainless Steel (Type 410)	Moderate	50	Straw	White	Moderate	Forked
10. Tungsten-Chromium Die Steel	Small	35	Red	Straw†	Many	Fine, repeating†
11. Nitrided Nitralloy	Large (curved)	55	White	White	Moderate	Forked
12. Stellite®	Very small	10	Orange	Orange	None	
13. Cemented Tungsten Carbide	Extremely small	2	Light Orange	Light Orange	None	
14. Nickel	Very small‡	10	Orange	Orange	None	
15. Copper, Brass, and Aluminum	None				None	

* actual length varies with grinding wheel, pressure, etc.
† blue-white spurts
‡ some wavy streaks

BRINELL HARDNESS NUMBERS*

Impression Diameter (mm)	Brinell Hardness Number For a Load of Kg. 500	1000	1500	2000	2500	3000	Impression Diameter (mm)	Brinell Hardness Number For a Load of Kg. 500	1000	1500	2000	2500
2.00	158	316	473	632	788	945	4.25	33.6	67.2	101	134	167
2.05	150	300	450	600	750	899	4.30	32.8	65.6	98.3	131	164
2.10	143	286	428	572	714	856	4.35	32.0	64.0	95.9	128	160
2.15	136	272	408	544	681	817	4.40	31.2	62.4	93.6	125	156
2.20	130	260	390	520	650	780	4.45	30.5	61.0	91.4	122	153
2.25	124	248	372	496	621	745	4.50	29.8	59.6	89.3	119	149
2.30	119	238	356	476	593	712	4.55	29.1	58.2	87.2	116	145
2.35	114	228	341	456	568	682	4.60	28.4	56.8	85.2	114	142
2.40	109	218	327	436	545	653	4.65	27.8	55.6	83.3	111	139
2.45	104	208	312	416	522	627	4.70	27.1	54.2	81.4	108	136
2.50	100	200	301	400	500	601	4.75	26.5	53.0	79.6	106	133
2.55	96.3	193	289	385	482	578	4.80	25.9	51.8	77.8	104	130
2.60	92.6	185	278	370	462	555	4.85	25.4	50.8	76.1	102	127
2.65	89.0	178	267	356	445	534	4.90	24.8	49.6	74.4	99.2	124
2.70	85.7	171	257	343	429	514	4.95	24.3	48.6	72.8	97.2	122
2.75	82.6	165	248	330	413	495	5.00	23.8	47.6	71.3	95.2	119
2.80	79.6	159	239	318	398	477	5.05	23.3	46.6	69.8	93.2	117
2.85	76.8	154	230	307	384	461	5.10	22.8	45.6	68.3	91.2	114
2.90	74.1	148	222	296	371	444	5.15	22.3	44.6	66.9	89.2	112
2.95	71.5	143	215	286	358	429	5.20	21.8	43.6	65.5	87.2	109
3.00	69.1	138	207	276	346	415	5.25	21.4	42.8	64.1	85.6	107
3.05	66.8	134	200	267	334	401	5.30	20.9	41.8	62.8	83.6	105
3.10	64.6	129	194	258	324	388	5.35	20.5	41.0	61.5	82.0	103
3.15	62.5	125	188	250	313	375	5.40	20.1	40.2	60.3	80.4	101
3.20	60.5	121	182	242	303	363	5.45	19.7	39.4	59.1	78.8	98.5
3.25	58.6	117	176	234	293	352	5.50	19.3	38.6	57.9	77.2	96.5
3.30	56.8	114	170	227	284	341	5.55	18.9	37.8	56.8	75.6	95.0
3.35	55.1	110	165	220	276	331	5.60	18.6	37.2	55.7	74.4	92.5
3.40	53.4	107	160	214	267	321	5.65	18.2	36.4	54.6	72.8	90.8
3.45	51.8	104	156	207	259	311	5.70	17.8	35.6	53.5	71.2	89.2
3.50	50.3	101	151	201	252	302	5.75	17.5	35.0	52.5	70.0	87.5
3.55	48.9	97.8	147	196	244	293	5.80	17.2	34.4	51.5	68.8	85.5
3.60	47.5	95.0	142	190	238	285	5.85	16.8	33.6	50.5	67.2	84.2
3.65	46.1	92.2	138	184	231	277	5.90	16.5	33.0	49.6	66.0	82.5
3.70	44.9	89.8	135	180	225	269	5.95	16.2	32.4	48.7	64.8	81.2
3.75	43.6	87.2	131	174	218	262	6.00	15.9	31.8	47.7	63.6	79.5
3.80	42.4	84.8	127	170	212	255	6.05	15.6	31.2	46.8	62.4	78.0
3.85	41.3	82.6	124	165	207	248	6.10	15.3	30.6	46.0	61.2	76.7
3.90	40.2	80.4	121	161	201	241	6.15	15.1	30.2	45.2	60.4	75.3
3.95	39.1	78.2	117	156	196	235	6.20	14.8	29.6	44.3	59.2	73.8

* diameter of ball=10mm

Tinius Olsen Testing Machine Company, Inc.

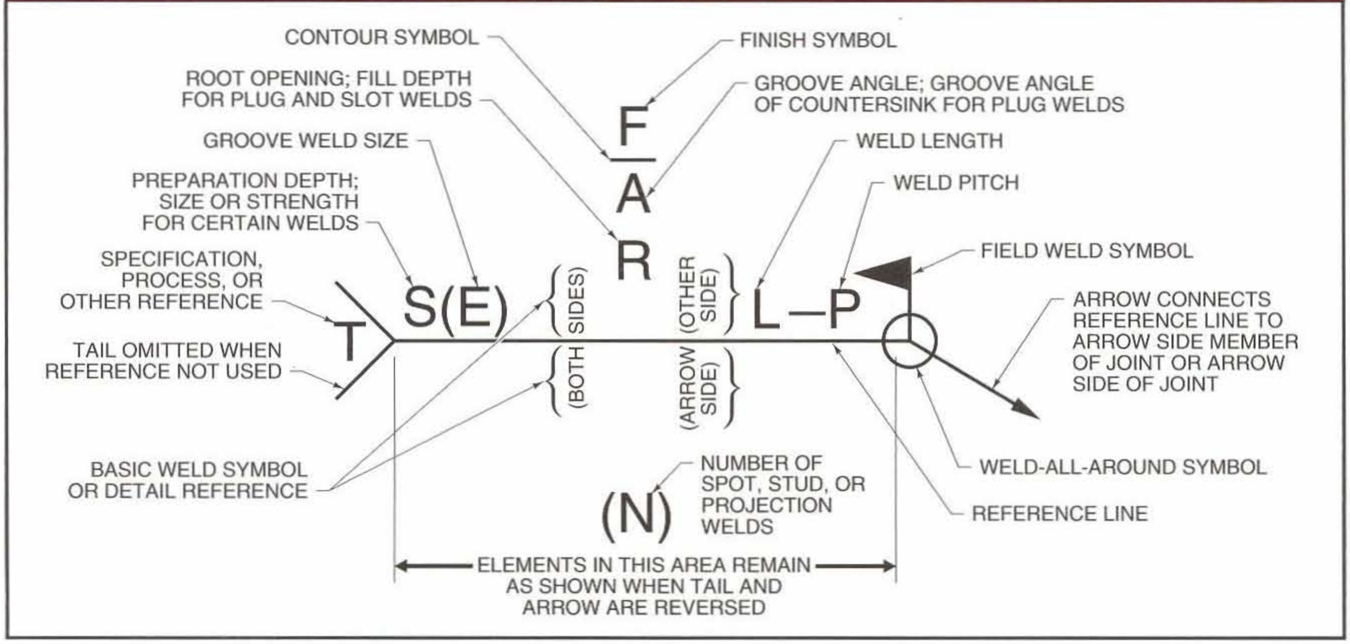
LOW-ALLOY, HIGH-STRENGTH ELECTRODES

Type/Suffix	Welding Application
E-7018-A1	Carbon and molybdenum steels
E-8016-B2 E-8018-B2L	Chromium—molybdenum steels
E-8016-C1 E-8018-C1 E-8018-C2 E-8018-C3	Nickel steels
E-9016-B3 E-9018-B3L	Chromium—molybdenum steels
E-10016-D2	Manganese—molybdenum steels

UNIT PREFIXES

PREFIX	UNIT	SYMBOL	NUMBER
	Other larger multiples		
Mega	Million	M	$1,000,000 = 10^6$
Kilo	Thousand	k	$1,000 = 10^3$
Hecto	Hundred	h	$100 = 10^2$
Deka	Ten	d	$10 = 10^1$
			Unit $1 = 10^0$
Deci	Tenth	d	$0.1 = 10^{-1}$
Centi	Hundredth	c	$0.01 = 10^{-2}$
Milli	Thousandth	m	$0.001 = 10^{-3}$
Micro	Millionth	μ	$0.000001 = 10^{-6}$
	Other smaller multiples		

WELDING SYMBOL



ELECTRODE SELECTION CHART*

Variables	Electrode Class†										
	E6010	E6011	E6012	E6013	E6027	E7014	E7024	E7016	E7018	E7028	E6020
Groove butt welds, flat (< ¼″)	5	5	3	8	10	9	9	7	9	10	10
Groove butt welds, all positions (< ¼″)	10	9	5	8	(b)	6	(b)	7	6	(b)	(b)
Fillet welds, flat or horizontal	2	3	8	7	9	9	10	5	9	9	10
Fillet welds, all positions	10	9	6	7	(b)	7	(b)	8	6	(b)	(b)
Current (C)‡	DCEP	DCEP AC	DCEN AC	DC AC	DC AC	DC AC	DC AC	DCEP AC	DCEP AC	DCEP AC	DC AC
Thin material (¼″)	5	7	8	9	(b)	8	7	2	2	(b)	(b)
Heavy plate or highly restrained joint	8	8	8	8	8	8	7	10	9	9	8
High-sulfur or off-analysis steel	(b)	(b)	5	3	(b)	3	5	9	9	9	(b)
Deposition rate	4	4	5	5	10	6	10	4	6	8	6
Depth of penetration	10	9	6	5	8	6	4	7	7	7	8
Appearance, undercutting	6	6	8	9	10	9	10	7	10	10	9
Soundness	6	6	3	5	9	7	8	10	9	9	9
Ductility	6	7	4	5	10	6	5	10	10	10	10
Low-temperature impact strength	8	8	4	5	9	8	9	10	10	10	8
Low spatter loss	1	2	6	7	10	9	10	6	8	9	9
Poor fit-up	6	7	10	8	(b)	9	8	4	4	4	(b)
Welder appeal	7	6	8	9	10	10	10	6	8	9	9
Slag removal	9	8	6	8	9	8	9	4	7	8	9

* Rating is on a comparative basis of same-size electrodes with 10 as the highest value. Ratings may change with size
† AWS
‡ DCEP–direct current electrode positive; DCEN–direct current electrode negative; AC–alternating current; DC–direct current, either polarity
(b) Not recommended

ROCKWELL HARDNESS CONVERSION TABLE...

Rockwell			Superficial Rockwell			Vickers	Knoop	Brinell	Tensile Strength	Brinell
B 100 kgf 1/16″ ball	A 60 kgf diamond	E 100 kgf 1/8″ ball	15T 15 kgf 1/16″ ball	30T 30 kgf 1/16″ ball	45T 45 kgf 1/16″ ball	Hardness	Hardness 500 gf and over	Hardness 3000 gf 10mm ball	1000 lbs square inch	Hardness 500 kgf 10mm ball
100	61.5	—	93.1	83.1	729	240	251	240	116	201
99	60.9	—	92.8	82.5	719	234	246	234	114	195
98	60.2	—	92.5	81.8	709	228	241	228	109	189
97	59.5	—	92.1	81.1	699	222	236	222	105	184
96	58.9	—	91.8	80.4	689	216	231	216	102	179
95	58.3	—	91.5	79.8	67.9	210	226	210	100	175
94	57.6	—	91.2	79.1	66.9	205	221	205	98	171
93	57.0	—	90.8	78.4	65.9	200	216	200	94	167
92	56.4	—	90.5	77.8	64.8	195	211	195	92	163
91	55.8	—	90.2	77.1	63.8	190	206	190	90	160
90	55.2	—	89.9	76.4	62.8	185	201	185	89	157
89	54.6	—	89.5	75.8	61.8	180	196	180	88	154
88	54.0	—	89.2	75.1	60.8	176	192	176	86	151
87	53.4	—	88.9	74.4	59.8	172	188	172	84	148
86	52.8	—	88.6	73.8	58.8	169	184	169	83	145
85	52.3	—	88.2	73.1	57.8	165	180	165	82	142
84	51.7	—	87.9	72.4	56.8	162	176	162	81	140
83	51.1	—	87.6	71.8	55.8	159	173	159	80	137
82	50.6	—	87.3	71.1	54.8	156	170	156	76	135
81	50.0	—	86.9	70.4	53.8	153	167	153	73	133
80	49.5	—	86.6	69.7	52.8	150	164	150	72	130
79	48.9	—	86.3	69.1	51.8	147	161	147	70	128
78	48.4	—	86.0	68.4	50.8	144	158	144	69	126
77	47.9	—	85.6	67.7	49.8	141	155	141	68	124
76	47.3	—	85.3	67.1	48.8	139	152	139	67	122
75	46.8	—	85.0	66.4	47.8	137	150	137	66	120
74	46.3	—	84.7	65.7	46.8	135	147	135	65	118
73	45.8	—	84.3	65.1	45.8	132	145	132	64	116
72	45.3	—	84.0	64.4	44.8	130	143	130	63	114
71	44.8	100	83.7	63.7	43.8	127	141	127	62	112
70	44.3	99.5	83.4	63.1	42.8	125	139	125	61	110
69	43.8	99.0	83.0	62.4	41.8	123	137	123	60	109
68	43.3	98.0	82.7	61.7	40.8	121	135	121	59	108
67	42.8	97.5	82.4	61.0	39.8	119	133	119	58	106
66	42.3	97.0	82.1	60.4	38.7	117	131	117	57	104
65	41.8	96.0	81.8	59.7	37.7	116	129	116	56	102
64	41.4	95.5	81.4	59.0	36.7	114	127	114	—	100
63	40.9	95.0	81.1	58.4	35.7	112	125	112	—	99
62	40.4	94.5	80.8	57.7	34.7	110	124	110	—	98
61	40.0	93.5	80.5	57.0	33.7	108	122	108	—	96
60	39.5	93.0	80.1	56.4	32.7	107	120	107	—	95
59	39.0	92.5	79.8	55.7	31.7	106	118	106	—	94
58	38.6	92.0	79.5	55.0	30.7	104	117	104	—	92
57	38.1	91.0	79.2	54.4	29.7	103	115	103	—	91
56	37.7	90.5	78.8	53.7	28.7	101	114	101	—	90
55	37.2	90.0	78.5	53.0	27.7	100	112	100	—	89
54	36.8	89.5	78.2	52.4	26.7	—	111	—	—	87
53	36.3	89.0	77.9	51.7	25.7	—	110	—	—	86
52	35.9	88.0	77.5	51.0	24.7	—	109	—	—	85
51	35.5	87.5	77.2	50.3	23.7	—	108	—	—	84
50	35.0	87.0	76.9	49.7	22.7	—	107	—	—	83
49	34.6	86.5	76.6	49.0	21.7	—	106	—	—	82
48	34.1	85.5	76.2	48.3	20.7	—	105	—	—	81
47	33.7	85.0	75.9	47.7	19.7	—	104	—	—	80
46	33.3	84.5	75.6	47.0	18.7	—	103	—	—	80

...ROCKWELL HARDNESS CONVERSION TABLE

Rockwell			Superficial Rockwell			Vickers	Knoop	Brinell	Tensile Strength	Brinell
B 100 kgf 1/16″ ball	A 60 kgf diamond	E 100 kgf 1/8″ ball	15T 15 kgf 1/16″ ball	30T 30 kgf 1/16″ ball	45T 45 kgf 1/16″ ball	Hardness	Hardness 500 gf and over	Hardness 3000 gf 10mm ball	1000 lbs square inch	Hardness 500 kgf 10mm ball
45	32.9	84.0	75.3	46.3	17.7	—	102	—	—	79
44	32.4	83.5	74.9	45.7	16.7	—	101	—	—	78
43	32.0	82.5	74.6	45.0	15.7	—	100	—	—	77
42	31.6	82.0	74.3	44.3	14.7	—	99	—	—	76
41	31.2	81.5	74.0	43.7	13.6	—	98	—	—	75
40	30.7	81.0	73.6	43.0	12.6	—	97	—	—	75
39	30.3	80.0	73.3	42.3	11.6	—	96	—	—	74
38	29.9	79.5	73.0	41.6	10.6	—	95	—	—	73
37	29.5	79.0	72.7	41.0	9.6	—	94	—	—	72
36	29.1	78.5	72.3	40.3	8.6	—	93	—	—	72
35	28.7	78.0	72.0	39.6	7.6	—	92	—	—	71
34	28.2	77.0	71.7	39.0	6.6	—	91	—	—	70
33	27.8	76.5	71.4	38.3	5.6	—	90	—	—	69
32	27.4	76.0	71.0	37.6	4.6	—	89	—	—	69
31	27.0	75.5	70.7	37.0	3.6	—	88	—	—	68
30	26.6	75.0	70.4	36.3	2.6	—	87	—	—	67

MILLIMETER AND DECIMAL INCH EQUIVALENTS*

mm in.	mm in.	mm in.	mm in.	mm in.	mm in.
1/50 = .00079	25/50 = .01969	1 = .03937	26 = 1.02362	51 = 2.00787	76 = 2.99212
2/50 = .00157	26/50 = .02047	2 = .07874	27 = 1.06299	52 = 2.04724	77 = 3.03149
3/50 = .00236	27/50 = .02126	3 = .11811	28 = 1.10236	53 = 2.08661	78 = 3.07086
4/50 = .00315	28/50 = .02205	4 = .15748	29 = 1.14173	54 = 2.12598	79 = 3.11023
	29/50 = .02283				
5/50 = .00394	30/50 = .02362	5 = .19685	30 = 1.18110	55 = 2.16535	80 = 3.14960
6/50 = .00472	31/50 = .02441	6 = .23622	31 = 1.22047	56 = 2.20472	81 = 3.18897
7/50 = .00551	32/50 = .02520	7 = .27559	32 = 1.25984	57 = 2.24409	82 = 3.22834
8/50 = .00630	33/50 = .02598	8 = .31496	33 = 1.29921	58 = 2.28346	83 = 3.26771
9/50 = .00709	34/50 = .02677	9 = .35433	34 = 1.33858	59 = 2.32283	84 = 3.30708
10/50 = .00787	35/50 = .02756	10 = .39370	35 = 1.37795	60 = 2.36220	85 = 3.34645
11/50 = .00866	36/50 = .02835	11 = .43307	36 = 1.41732	61 = 2.40157	86 = 3.38582
12/50 = .00945	37/50 = .02913	12 = .47244	37 = 1.45669	62 = 2.44094	87 = 3.42519
13/50 = .01024	38/50 = .02992	13 = .51181	38 = 1.49606	63 = 2.48031	88 = 3.46456
14/50 = .01102	39/50 = .03071	14 = .55118	39 = 1.53543	64 = 2.51968	89 = 3.50393
15/50 = .01181	40/50 = .03150	15 = .59055	40 = 1.57480	65 = 2.55905	90 = 3.54330
16/50 = .01260	41/50 = .03228	16 = .62992	41 = 1.61417	66 = 2.59842	91 = 3.58267
17/50 = .01339	42/50 = .03307	17 = .66929	42 = 1.65354	67 = 2.63779	92 = 3.62204
18/50 = .01417	43/50 = .03386	18 = .70866	43 = 1.69291	68 = 2.67716	93 = 3.66141
19/50 = .01496	44/50 = .03465	19 = .74803	44 = 1.73228	69 = 2.71653	94 = 3.70078
20/50 = .01575	45/50 = .03543	20 = .78740	45 = 1.77165	70 = 2.75590	95 = 3.74015
21/50 = .01654	46/50 = .03622	21 = .82677	46 = 1.81102	71 = 2.79527	96 = 3.77952
22/50 = .01732	47/50 = .03701	22 = .86614	47 = 1.85039	72 = 2.83464	97 = 3.81889
23/50 = .01811	48/50 = .03780	23 = .90551	48 = 1.88976	73 = 2.87401	98 = 3.85826
24/50 = .01890	49/50 = .03858	24 = .94488	49 = 1.92913	74 = 2.91338	99 = 3.89763
		25 = .98425	50 = 1.96850	75 = 2.95275	100 = 3.93700

*Based on 1/100 mm = .003973″ 10 mm = 1 centimeter = 0.3937″ 25.4 mm = 1″
10 cm = 1 decimeter = 3.937″ 10 dm = 1 meter = 39.37″

Form A.7.1

SUGGESTED
WELDING PROCEDURE SPECIFICATION (WPS)

Identification ______________

Date ______________ Revision ______________

Company name ______________

Supporting PQR no.(s) ______________ Type - Manual ( ) Semiautomatic ( )

Welding process(es) ______________ Mechanized ( ) Automatic ( )

Backing: Yes ( ) No ( )

Backing material (type) ______________

Material number ______________ Group ______________ To material number ______________ Group ______________

Material spec. type and grade ______________ To material spec. type and grade ______________

Base metal thickness range: Groove ______________ Fillet ______________

Deposited weld metal thickness range ______________

Filler metal F no. ______________ A no. ______________

Spec. no. (AWS) ______________ Flux tradename ______________

Electrode-flux (Class) ______________ Type ______________

Consumable insert: Yes ( ) No ( ) Classifications ______________

Shape ______________

Position(s) of joint ______________ Size ______________

Welding progression: Up ( ) Down ( ) Ferrite number (when reqd.) ______________

PREHEAT:

Preheat temp., min ______________

Interpass temp., max ______________
(continuous or special heating, where applicable, should be recorded)

GAS:

Shielding gas(es) ______________

Percent composition ______________

Flow rate ______________

Root shielding gas ______________

Trailing gas composition ______________

Trailing gas flow rate ______________

POSTWELD HEAT TREATMENT:

Temperature range ______________

Time range ______________

Tungsten electrode, type and size ______________

Mode of metal transfer for GMAW: Short-circuiting ( ) Globular ( ) Spray ( )

Electrode wire feed speed range: ______________

Stringer bead ( ) Weave bead ( ) Peening: Yes ( ) No ( )

Oscillation ______________

Standoff distance

Multiple ( ) or single electrode ( )

Other ______________

	Filler metal				Current			
Weld layer(s)	Process	Class	Dia.	Type & polarity	Amp range	Volt range	Travel speed range	
								e.g., Remarks, comments, hot wire addition, technique, torch angle, etc.

Approved for Production by ______________
Employer

Note: Those items that are not applicable should be marked N.A.

American Welding Society

Form A.7.2

SUGGESTED PROCEDURE QUALIFICATION RECORD (PQR)

WPS no. used for test ____________________

Company ____________________

Welding process(es) ____________________

Equipment type and model (sw) ____________________

JOINT DESIGN USED (2.6.1)

Single ( ) Double weld ( )

Backing material ____________________

Root opening ______ Root face dimension ______

Groove angle ______ Radius (J-U) ______

Back gouging: Yes ( ) No ( ) Method ______

BASE METALS (2.6.2)

Material spec. ______ To ______

Type or grade ______ To ______

Material no. ______ To material no. ______

Group no. ______ To group no. ______

Thickness ____________________

Diameter (pipe) ____________________

Surfacing: Material ______ Thickness ______

Chemical composition ____________________

Other ____________________

FILLER METALS (2.6.3)

Weld metal analysis A no. ____________________

Filler metal F no. ____________________

AWS specification ____________________

AWS classification ____________________

Flux class ______ Flux brand ______

Consumable insert: Spec. ______ Class. ______

Supplemental filler metal spec. ______ Class. ______

Non-classified filler metals ____________________

Consumable guide (ESW) Yes ( ) No ( )

Supplemental deoxidant (EBW) ____________________

POSITION (2.6.4)

Position of groove ______ Fillet ______

Vertical progression: Up ( ) Down ( )

PREHEAT (2.6.5)

Preheat temp., actual min. ____________________

Interpass temp., actual max. ____________________

WELD INCREMENT SEQUENCE

HEAT POSTWELD TREATMENT (2.6.6)

Temp. ____________________

Time ____________________

Other ____________________

GAS (2.6.7)

Gas type(s) ____________________

Gas mixture percentage

Flow rate ____________________

Backing gas ______ Flow rate ______

Root shielding gas

EBW vacuum ( ) Absolute pressure ( )

ELECTRICAL CHARACTERISTICS (2.6.8)

Electrode extension ____________________

Standoff distance

Transfer mode (GMAW) ____________________

Electrode diameter tungsten ____________________

Type tungsten electrode ____________________

Current: AC ( ) DCEP ( ) DCEN ( ) Pulsed ( )

Heat input ____________________

EBW: beam focus current ______ Pulse freq. ______

Filament type ______ Shape ___ Size ______

Other ____________________

TECHNIQUE (2.6.9)

Oscillation frequency ______ Weave width ______

Dwell time ____________________

String or weave bead ______ Weave width ______

Multiple-pass or single pass (per side) ____________________

Number of electrodes ____________________

Peening ____________________

Electrode spacing ____________________

Arc timing (SW) ______ Lift ( )

PAW: Conventional ( ) Key hole ( )

Interpass cleaning:

Pass no.	Filler metal size	Amps	Volts	Travel speed (ipm)	Filler metal wire (ipm)	Slope induction	Special notes (process, etc.)

Note: Those items that are not applicable should be marked N.A.

American Welding Society

TENSILE TEST SPECIMENS: SUGGESTED PROCEDURE QUALIFICATION RECORD PQR No.

Type: ______ Tensile specimen size: ______ Area: ______

Groove ( ) Reinforcing bar ( ) Stud welds ( )

Tensile test results: (Minimum required UTS ______ psi)

Specimen no.	Width, in.	Thickness, in.	Area, in.^{2}	Max load lb	UTS, psi	Type failure and location

GUIDED BEND TEST SPECIMENS - SPECIMEN SIZE: ______

Type	Result	Type	Result

MACRO-EXAMINATION RESULTS: Reinforcing bar ( ) Stud ( )

1. ______ 4. ______
2. ______ 5. ______
3. ______

SHEAR TEST RESULTS - FILLETS:

1. ______ 3. ______
2. ______ 4. ______

IMPACT TEST SPECIMENS

Type: ______ Size: ______

Test temperature: ______

Specimen location: WM = weld metal; BM = base metal; HAZ = heat-affected zone

Test results:

Welding position	Specimen location	Energy absorbed (ft.-lb)	Ductile fracture area (percent)	Lateral expansion (mils)

IF APPLICABLE **RESULTS**

Hardness tests: ( ) Values ______	Acceptable ( )	Unacceptable ( )
Visual (special weldments 2.4.2) ( )	Acceptable ( )	Unacceptable ( )
Torque ( ) psi	Acceptable ( )	Unacceptable ( )
Proof test ( ) Method ______	Acceptable ( )	Unacceptable ( )
Chemical analysis ( )	Acceptable ( )	Unacceptable ( )
Nondestructive exam ( ) Process ______	Acceptable ( )	Unacceptable ( )
Other ______	Acceptable ( )	Unacceptable ( )

Mechanical testing by (Company) ______ Lab No. ______

We certify that the statements in this Record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of the American Welding Society Standard for Welding Procedure and Performance Qualification (AWS B2-83)

Qualifier: ______ Reviewed by: ______

Date: ______ Approved by: ______

Employer

American Welding Society

Form A.7.3

SUGGESTED
PERFORMANCE QUALIFICATION TEST RECORD

Name ______________________ Identification ______________________ Welder ( ) Operator ( )

Social security number: ______________________ Qualified to WPS no. ______________

Process(es) ____________ Manual ( ) Semiautomatic ( ) Automatic ( ) Mechanized ( )

Test base metal specification ______________________ To ______________

Material number ______________________ To ______________

Fuel gas (OFW) ______________________

AWS filler metal classification ______________________ F no. ______________

Backing:	Yes	( )	No	( )	Double ( ) or Single side ( )
Current:	AC	( )	DC	( )	Short circuiting transfer (GMAW) Yes (..) No (..)
Consumable insert:	Yes	( )	No	( )	
Root shielding:	Yes	( )	No	( )	

TEST WELDMENT **POSITION TESTED** **WELDMENT THICKNESS (T)**

GROOVE:

Pipe	1G ( )	2G ( )	5G ( )	6G ( )	6GR ( )	Diameter(s) ________ (T) ______
Plate	1G ( )	2G ( )	3G ( )	4G ( )		(T) ______________
Rebar	1G ( )	2G ( )	3G ( )	4G ( )		Bar size ________ Butt ( ) Spliced butt ( )

FILLET:

Pipe ( )	1F ( )	2F ( )	3F ( )		5F ( )	Diameter ________ (T) ______
Plate ( )	1F ( )	2F ( )	3F ( )	4F ( )		(T) ______

Other (describe) ______________________

Test results: Remarks

Visual test	N/A ( )	Pass ( )	Fail ( )
Bend test	N/A ( )	Pass ( )	Fail ( )
Macro test	N/A ( )	Pass ( )	Fail ( )
Tension test	N/A ( )	Pass ( )	Fail ( )
Radiographic test	N/A ( )	Pass ( )	Fail ( )
Penetrant test	N/A ( )	Pass ( )	Fail ( )

QUALIFIED FOR:
PROCESSES
GROOVE: **THICKNESS**

Pipe	1G ( )	2G ( )	5G ( )	6G ( )	6GR ( )	(T) Min ______ Max. ______ Dia ______
Plate	1G ( )	2G ( )	3G ( )	4G ( )		(T) Min ______ Max. ______
Rebar	1G ( )	2G ( )	3G ( )	4G ( )		Bar size Min ______ Max. ______

FILLET:

Pipe	1F ( )	2F ( )	4F ( )	5F ( )	(T) Min ______ Max. ______
Plate	1F ( )	2F ( )	3F ( )	4F ( )	(T) Min ______ Max. ______
Rebar	1F ( )	2F ( )	3F ( )	4F ( )	Bar size Min ______ Max. ______

Weld cladding ( ) Position(s) ____________ T Min ______ Max. ______ Clad Min ______

Consumable insert ( ) Backing type ( )
Uphill ( ) Downhill ( )
Single side ( ) Double side ( ) No backing ( )
Short circuiting ( ) ( ) Spray ( ) Pulsed Spray ( )
Reinforcing bar - butt ( ) or Spliced butt ( )

The above named person is qualified for the welding process(es) used in this test within the limits of essential variables including materials and filler metal variables of the AWS Standard for Welding Procedure and Performance Qualification (AWS B2.1).

Date tested ______________________ Signed by ______________________
Qualifier

American Welding Society

AISI-SAE DESIGNATION SYSTEM

Numbers and Digits	Type of steel and/or nominal alloy content
Carbon steels	
10xx	— Plain carbon (1% Mn max)
11xx	— Resulfurized
12xx	— Resulfurized and rephosphorized
15xx	— Plain carbon (1.00% Mn to 1.65% Mn max)
Manganese steels	
13xx	— 1.75% Mn
Nickel steels	
23xx	— 3.5% Ni
25xx	— 5% Ni
Nickel-chromium steels	
31xx	— 1.25% Ni; .65% Cr and .80% Cr
32xx	— 1.75% Ni; 1.07% Cr
33xx	— 3.50% Ni; 1.50% Cr and 1.57% Cr
34xx	— 3.00% Ni; .77% Cr
Molybdenum steels	
40xx	— .20% Mo and .25% Mo
44xx	— .40% Mo and .52% Mo
Chromium-molybdenum steels	
41xx	— .50% Cr, .80% Cr, and .95% Cr; .12% Mo, .20% Mo, .25% Mo, and .30% Mo
Nickel-chromium-molybdenum steels	
43xx	— 1.82% Ni; .50% Cr and .80% Cr; .25% Mo
43BVxx	— 1.82% Ni; .50% Cr; .12% Mo and .25% Mo; .03% V min
47xx	— 1.05% Ni; .45% Cr; .20% Mo and .35% Mo
81xx	— .30% Ni; .40% Cr; .12% Mo
86xx	— .55% Ni; .50% Cr; .20% Mo
87xx	— .55% Ni; .50% Cr; .25% Mo
88xx	— .55% Ni; .50% Cr; .35% Mo
93xx	— 3.25% Ni; 1.20% Cr; .12% Mo
94xx	— .45% Ni; .40% Cr; .12% Mo
97xx	— .55% Ni; .20% Cr; .20% Mo
98xx	— 1.00% Ni; .80% Cr; .25% Mo
Nickel-molybdenum steels	
46xx	— .85% Ni and 1.82% Ni; .20% Mo and .25% Mo
48xx	— 3.50% Ni; .25% Mo
Chromium steels	
50xx	— .27% Cr, .40% Cr, .50% Cr, and .65% Cr
51xx	— .80% Cr, .87% Cr, .92% Cr, .95% Cr, 1.00% Cr, and 1.05% Cr
Chromium steels	
50xxx	— .50% Cr } C 1.00% min
51xxx	— 1.02% Cr } C 1.00% min
52xxx	— 1.45% Cr } C 1.00% min
Chromium-vanadium steels	
61xx	— .60% Cr, .80% Cr, and .95% Cr; .10% V and .15% V min
Tungsten-chromium steel	
72xx	— 1.75% W; 0.75% Cr
Silicon-manganese steels	
92xx	— 1.40% Si and 2.00% Si; .65% Mn, .82% Mn, and .85% Mn; 0% Cr and .65% Cr
High-strength low-alloy steels	
9xx	— Various SAE grades
Boron steels	
xxBxx	— B denotes boron steel
Leaded steels	
xxLxx	— L denotes leaded steel

ASTM SPECIFICATIONS FOR CHROME-MOLY STEEL PRODUCTS					
Type	Forgings	Tubes	Pipe	Castings	Plate
½ Cr-½ Mo	A182-F2	A213-T2	A335-P2 A369-FP2 A426-CP2	A356-GR5	A387-Gr2
1 Cr-½ Mo	A182-F12 A336-F12	A213-T12	A335-P12 A369-FP12 A426-CP12	—	A387-Gr2
1¼ Cr-½ Mo	A182-F11/F11A A336-F11/F11A	A199-T11 A200-T11 A213-T11	A335-P11 A369-FP11 A426-CP11	A217-WC6/11 A356-Gr6 A389-C23	A387-Gr11
2¼ Cr-1 Mo	A182-F22/F22a A336-F22/F22A	A199-T22 A200-T22 A213-T22	A335-P22 A369-FP22 A426-CP22	A217-WC9 A356-Gr10	A387-Gr22
3 Cr-1 Mo	A182-F21 A336-F21/F21A	A199-T21 A200-T21 A213-T21	A335-P21 A369-FP21 A426-CP21	—	A387-Gr21
5 Cr-½ Mo	A182-F5/F5a A336-F5/F5A	A199-T5 A200-T5 A213-T5	A335-P5 A369-FP5 A426-CP5	A217-C5	A387-Gr5
5 Cr-½ MoSi	—	A213-T5b	A335-P5b A426-CP5b	—	—
5 Cr-½ MoTi	—	A213-T5c	A335-P5c	—	—
7 Cr-½ Mo	A182-F7	A199-T7 A200-T7 A213-T7	A335-P7 A369-FP7 A426-CP7	—	A387-Gr7
9 Cr-1 Mo	A182-F9 A336-F9	A199-T9 A200-T9 A213-T9	A335-P9 A369-FP9 A426-CP9	A217-C12	A387-Gr9
9 Cr-1 Mo and V+Nb+N	A182-F91	A199-T91 A200-T91 A213-T91	A335-P91 A369-FP91	—	A387-Gr91

DECIMAL INCH EQUIVALENTS*							
Fraction	Decimal	Fraction	Decimal	Fraction	Decimal	Fraction	Decimal
$^{1}/_{64}$	0.015625	$^{17}/_{64}$	0.265625	$^{33}/_{64}$	0.515625	$^{47}/_{64}$	0.765625
$^{1}/_{32}$	0.03125	$^{9}/_{32}$	0.28125	$^{17}/_{32}$	0.53125	$^{25}/_{32}$	0.78125
$^{3}/_{64}$	0.046875	$^{19}/_{64}$	0.296875	$^{35}/_{64}$	0.546875	$^{51}/_{64}$	0.796875
$^{1}/_{16}$	0.0625	$^{5}/_{16}$	0.3125	$^{9}/_{16}$	0.5625	$^{13}/_{16}$	0.8125
$^{5}/_{64}$	0.078125	$^{21}/_{64}$	0.328125	$^{37}/_{64}$	0.578125	$^{53}/_{64}$	0.828125
$^{3}/_{32}$	0.09375	$^{11}/_{32}$	0.34375	$^{19}/_{32}$	0.59375	$^{27}/_{32}$	0.84375
$^{7}/_{64}$	0.109375	$^{23}/_{64}$	0.359375	$^{39}/_{64}$	0.609375	$^{55}/_{64}$	0.859375
$^{1}/_{8}$	0.125	$^{3}/_{8}$	0.375	$^{5}/_{8}$	0.625	$^{7}/_{8}$	0.875
$^{9}/_{64}$	0.140625	$^{25}/_{64}$	0.390625	$^{41}/_{64}$	0.640625	$^{57}/_{64}$	0.890625
$^{5}/_{32}$	0.15625	$^{13}/_{32}$	0.40625	$^{21}/_{32}$	0.65625	$^{29}/_{32}$	0.90625
$^{11}/_{64}$	0.171875	$^{27}/_{64}$	0.421875	$^{43}/_{64}$	0.671875	$^{59}/_{64}$	0.921875
$^{3}/_{16}$	0.1875	$^{7}/_{16}$	0.4375	$^{11}/_{16}$	0.6875	$^{15}/_{16}$	0.9375
$^{13}/_{64}$	0.203125	$^{29}/_{64}$	0.453125	$^{45}/_{64}$	0.703125	$^{61}/_{64}$	0.953125
$^{7}/_{32}$	0.21875	$^{15}/_{32}$	0.46875	$^{23}/_{32}$	0.71875	$^{31}/_{32}$	0.96875
$^{15}/_{64}$	0.234375	$^{31}/_{64}$	0.484375	$^{47}/_{64}$	0.734375	$^{63}/_{64}$	0.984375

LIST OF MICROETCHANTS*

Alloy Family	Common Name for Etchant	ASTM E407 No.†
Carbon and low alloy steels	Nital or Picral	74a, 76
Tool steels	Nital	74a
Cast irons	Nital	74a
Austenitic stainless steels	Oxalic	13b
Precipitation hardening stainless steels	Fry's	79
Ferritic and martensitic stainless steels	Viella's	80
Heat resistant castings	Glyceregia	87
Ni, Ni-Cu, and Ni-Fe	Acetic-nitric-water	134
Ni-Mo	Chromic-HCl	143
Ni-Cr-Mo (Alloy C-276)	Oxalic	13c
Ni-Cr-Mo (all other)	Hydrochloric-methanol	23
Ni-Fe-Cr-Mo (Alloy 20 Cb-3)	Hydrochloric-nitric	88
Ni-Fe-Cr-Mo (all other)	Hydrochloric-copper sulfate	25
Ni and Fe base superalloys	Kalling's or Glyceregia	94, 87
W, Mo	Murakami's	98c
Ta, Cb	Sulfuric-HF-peroxide	163
Ti	Kroll's	192
Zr	Nitric-HF-hydrochloric	66
Al	Keller's	3
Mg	Acetic-glycol	119
Pb	Acetic-nitric-glycerin	113
Sn, Sn-Pb	Nital	74d
Zinc	Chromic-sodium sulfate	200
Cu alloys	Ammonium hydroxide-peroxide	44
Cu-Zn	Phosphoric-water	8b

* Exercise extreme caution in handling all chemicals, especially HF. Follow safety precautions described in ASTM E407.
† See numerical list of etchants

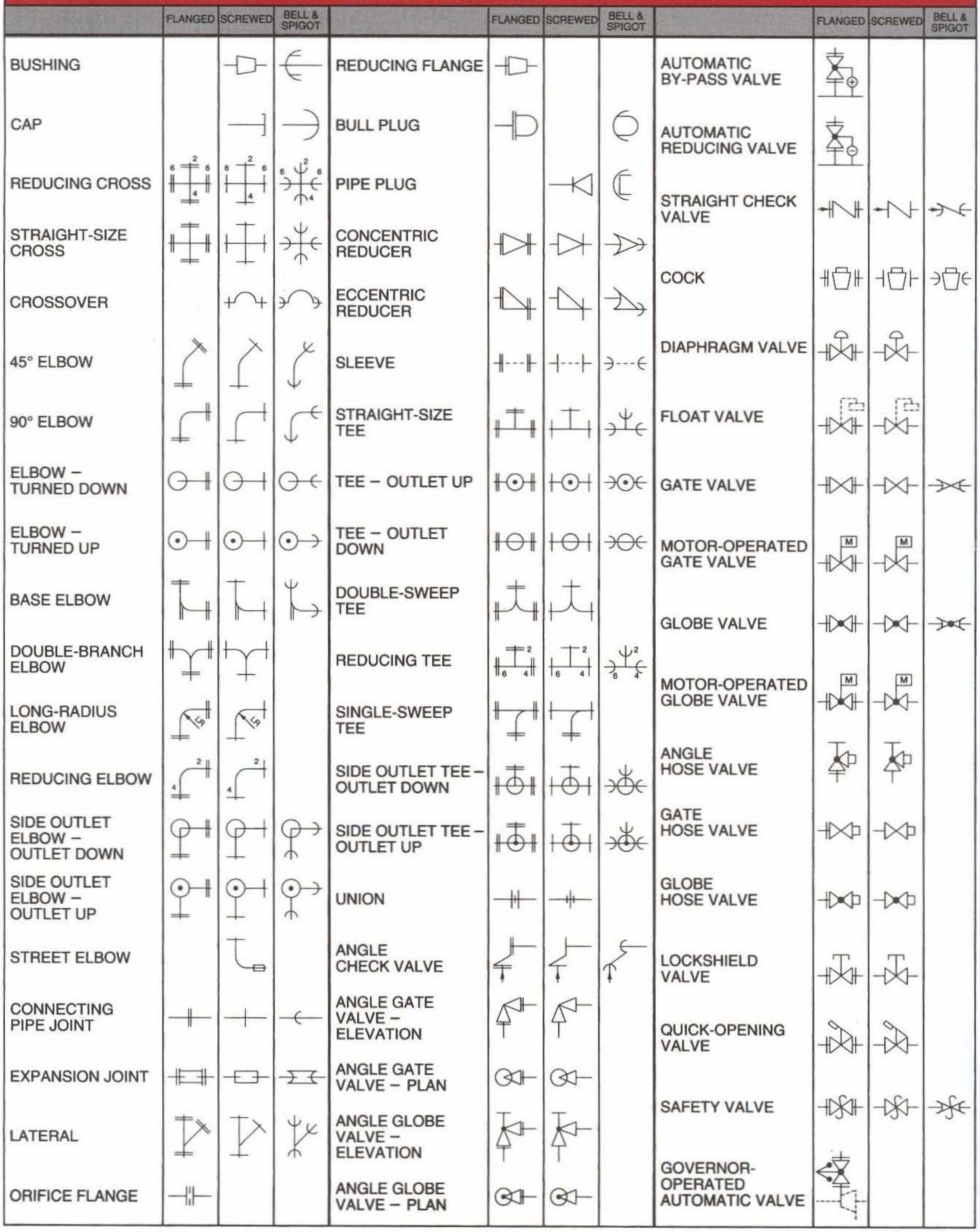
NUMERICAL LIST OF ETCHANTS...		
Etchant	**Composition**	**Procedure**
3	2 ml HF 3 ml HCl 5 ml HNO_3 190 ml water	(a) Immerse 10 to 20 sec. Wash in stream of warm water. Reveals general structure. (b) Dilute with four parts water—color constituents—mix fresh.
8 13	10 ml H_3PO_4 90 ml water 10 g oxalic acid 100 ml water	(b) Electrolytic at 1 V to 8 V for 5 to 10 sec. Electrolytic at 6 V. (b) 1 min (c) 2 to 3 sec
23	5 ml HCl 95 ml ethanol (95%) or methanol (95%)	Electrolytic at 6 V for 10 to 20 sec.
44	50 ml NH_4OH 20 to 50 ml H_2O_2 (3%) 0 to 50 ml water	Use fresh. Peroxide content varies directly with copper content of alloy to be etched. Swab or immerse up to 1 min. Film on etched aluminum bronze removed by No. 82.
66	30 ml HF 15 ml HNO_3 30 ml HCl	Swab 3 to 10 sec or immerse to 2 min.
74	1 to 5 ml HNO_3 100 ml ethanol (95%) or methanol (95%)	Etching rate is increased, selectivity decreased with increased percentage of HNO_3. (a) Immerse a few seconds to a minute. (d) Swab or immerse several minutes.
75	5 g picric acid 8 g $CuCl_2$ 20 ml HCl 6 ml HNO_3 200 ml ethanol (95%) or methanol (95%)	Immerse 1 to 2 sec at a time and immediately rinse with methanol. Repeat as often as necessary. Long immersion times result in copper deposition on surface.
76	10 g picric acid 10 ml ethanol (95%) or methanol (95%)	Composition given will saturate the solution with picric acid. Immerse a few seconds to a minute or more.
79	40 ml HCl 5 g $CuCl_2$ 30 ml water 25 ml ethanol (95%) or methanol (95%)	Swab a few seconds to a minute.
80	5 ml HCl 1 g picric acid 100 ml ethanol (95%) or methanol (95%)	Swab or immerse a few seconds to 15 min. Reaction may be accelerated by adding a few drops of 3% H_2O_2.
82	5 g $FeCl_3$ 5 drops HCl 100 ml water	Immerse 5 to 10 sec.
87	10 ml HNO_3 20 to 50 ml HCl 30 ml glycerin	**Warning:** Nitrogen dioxide gas given off. Use hood. Mix HCl and glycerin thoroughly before adding HNO_3. Do not store. Discard before solution attains a dark orange color. Swab or immerse a few seconds to a few minutes. Higher percentage of HCl minimizes pitting. A hot water rinse just prior to etching may be used to activate the reaction. Sometimes a few passes on the final polishing wheel is also necessary to remove a passive surface.

...NUMERICAL LIST OF ETCHANTS		
Etchant	**Composition**	**Procedure**
88	10 ml HNO_3 20 ml HCl 30 ml water	**Warning:** Nitrogen dioxide gas given off. Use hood. Discard before solution attains a dark orange color. Immerse a few seconds to a minute. Much stronger reaction than No. 87.
94	2 g $CuCl_2$ 40 ml HCl 40 to 80 ml ethanol (95%) or methanol (95%)	Submerged swabbing for a few seconds to several minutes.
98	10 g $K_3Fe(CN)_6$ 10 g KOH or NaOH 100 ml water	**Warning:** Extremely poisonous hydrogen cyanide given off. Use hood. Poisonous by ingestion as well as contact. To discard, neutralize (or turn basic) with ammonia and flush down acid drain with water. Use fresh. (c) Swab 5 to 60 sec. Immersion will produce a stain etch. Follow with water rinse, alcohol rinse, dry.
113	15 ml acetic acid 15 ml HNO_3 60 ml glycerin	Use fresh solution at 80°C (175°F).
119	1 ml HNO_3 20 ml acetic acid 60 ml diethylene glycol 20 ml water	Swab 1 to 3 sec for F and T6, 10 sec for T4 and 0 temper.
134	70 ml H_3PO_4 30 ml water	Electrolytic for 5 V to 10 V for 5 to 60 sec. Polishes at high currents.
143	0.01 to 1 g CrO_3 100 ml HCl	Allow solution to age a few minutes before using. Swab or immerse a few seconds to a few minutes.
163	30 ml H_2SO_4 30 ml HF 3 to 5 drops H_2O_2 (30%) 30 ml water	Immerse 5 to 60 sec. Use this solution for alternate etch and polishing.
192	1 to 3 ml HF 2 to 6 ml HNO_3 100 ml water	Swab 3 to 10 sec or immerse 10 to 30 sec. HF attacks and HNO_3 brightens the surface of titanium. Make concentation changes on this basis.
200	A– 40 g CrO_3 3 g $NaSO_4$ 200 ml water B– 40 g CrO_3 200 ml water	Immerse in Solution A with gentle agitation for several seconds. Rinse in Solution B.

LETTER SIZES*									
SIZE	DRILL DIAMETER	SIZE	DRILL DIAMETER	SIZE	DRILL DIAMETER	SIZE	DRILL DIAMETER	SIZE	DRILL DIAMETER
A	.234	G	.261	L	.290	Q	.332	V	.377
B	.238	H	.266	M	.295	R	.339	W	.386
C	.242	I	.272	N	.302	S	.348	X	.397
D	.246	J	.277	O	.316	T	.358	Y	.404
E	.250	K	.281	P	.323	U	.368	Z	.413
F	.257								

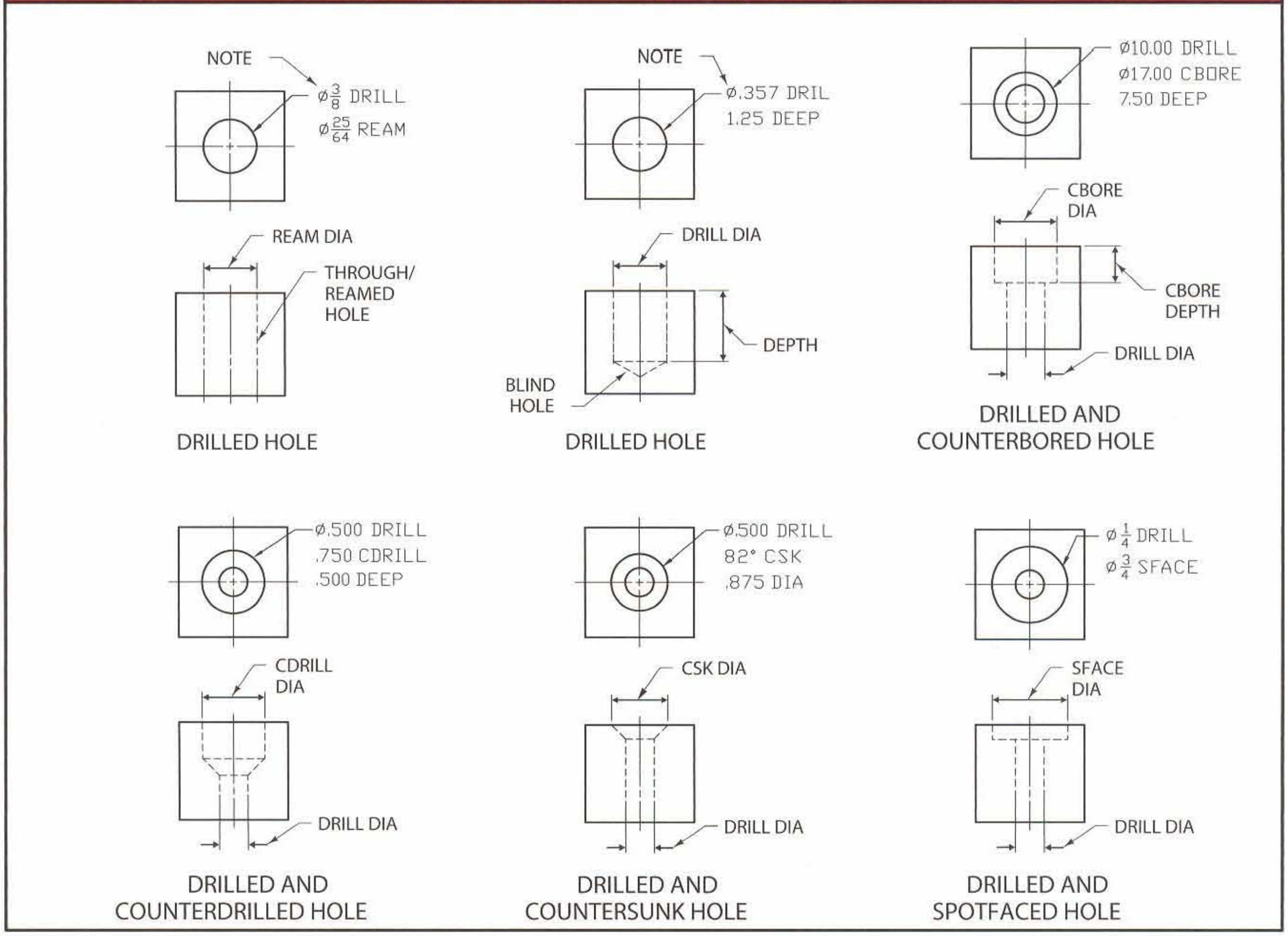
*in in.

PIPE FITTINGS AND VALVES



AMSE International

DRILLED HOLES



DRILL SIZES*

SIZE	DRILL DIAMETER	SIZE	DRILL DIAMETER	SIZE	DRILL DIAMETER	SIZE	DRILL DIAMETER	SIZE	DRILL DIAMETER	SIZE	DRILL DIAMETER
1	.2280	17	.1730	33	.1130	49	.0730	65	.0350	81	.0130
2	.2210	18	.1695	34	.1110	50	.0700	66	.0330	82	.0125
3	.2130	19	.1660	35	.1100	51	.0670	67	.0320	83	.0120
4	.2090	20	.1610	36	.1065	52	.0635	68	.0310	84	.0115
5	.2055	21	.1590	37	.1040	53	.0595	69	.0292	85	.0110
6	.2040	22	.1570	38	.1015	54	.0550	70	.0280	86	.0105
7	.2010	23	.1540	39	.0995	55	.0520	71	.0260	87	.0100
8	.1990	24	.1520	40	.0980	56	.0465	72	.0250	88	.0095
9	.1960	25	.1495	41	.0960	57	.0430	73	.0240	89	.0091
10	.1935	26	.1470	42	.0935	58	.0420	74	.0225	90	.0087
11	.1910	27	.1440	43	.0890	59	.0410	75	.0210	91	.0083
12	.1890	28	.1405	44	.0860	60	.0400	76	.0200	92	.0079
13	.1850	29	.1360	45	.0820	61	.0390	77	.0180	93	.0075
14	.1820	30	.1285	46	.0810	62	.0380	78	.0160	94	.0071
15	.1800	31	.1200	47	.0785	63	.0370	79	.0145	95	.0067
16	.1770	32	.1160	48	.0760	64	.0360	80	.0135	96	.0063

*in in.

STANDARD SERIES THREADS — GRADED PITCHES						
NOMINAL DIAMETER	UNC		UNF		UNEF	
	TPI	TAP DRILL	TPI	TAP DRILL	TPI	TAP DRILL
0 (.0600)			80	3/64		
1 (.0730)	64	No. 53	72	No. 53		
2 (.0860)	56	No. 50	64	No. 50		
3 (.0990)	48	No. 47	56	No. 45		
4 (.1120)	40	No. 43	48	No. 42		
5 (.1250)	40	No. 38	44	No. 37		
6 (.1380)	32	No. 36	40	No. 33		
8 (.1640)	32	No. 29	36	No. 29		
10 (.1900)	24	No. 25	32	No. 21		
12 (.2160)	24	No. 16	28	No. 14	32	No.13
1/4 (.2500)	20	No. 7	28	No. 3	32	7/32
5/16 (.3125)	18	F	24	I	32	9/32
3/8 (.3750)	16	5/16	24	Q	32	11/32
7/16 (.4375)	14	U	20	25/64	28	13/32
1/2 (.5000)	13	27/64	20	29/64	28	15/32
9/16 (.5625)	12	31/64	18	33/64	24	33/64
5/8 (.6250)	11	17/32	18	37/64	24	37/64
11/16 (.6875)					24	41/64
3/4 (.7500)	10	21/32	16	11/16	20	45/64
13/16 (.8125)					20	49/64
7/8 (.8750)	9	49/64	14	13/16	20	53/64
15/16 (.9375)					20	57/64
1 (1.000)	8	7/8	12	59/64	20	61/64

PREFERRED METRIC SCREW THREADS							
COARSE (GENERAL PURPOSE)				FINE			
Nominal Size and Thd Pitch	Tap Drill Diameter*	Nominal Size and Thd Pitch	Tap Drill Diameter*	Nominal Size and Thd Pitch	Tap Drill Diameter*	Nominal Size and Thd Pitch	Tap Drill Diameter*
M1.6 x 0.35	1.25	M20 x 2.5	17.5	—	—	M20 x 1.5	18.5
M2 x 0.4	1.6	M24 x 3	21.0	—	—	M24 x 2	22.0
M2.5 x 0.45	2.05	M30 x 3.5	26.5	—	—	M30 x 2	28.0
M3 x 0.5	2.5	M36 x 4	32.0	—	—	M36 x 2	33.0
M4 x 0.7	3.3	M42 x 4.5	37.5	—	—	M42 x 2	39.0
M5 x 0.8	4.2	M48 x 5	43.0	—	—	M48 x 2	45.0
M6 x 1	5.0	M56 x 5.5	50.5	—	—	M56 x 2	52.0
M8 x 1.25	6.8	M64 x 6	58.0	M8 x 1	7.0	M64 x 2	60.0
M10 x 1.5	8.5	M72 x 6	66.0	M10 x 1.25	8.75	M72 x 2	68.0
M12 x 1.75	10.30	M80 x 6	74.0	M12 x 1.25	10.5	M80 x 2	76.0
M16 x 2	14.00	M90 x 6	84.0	M16 x 1.5	14.5	M90 x 2	86.0
—	—	M100 x 6	94.0	—	—	M100 x 2	96.0

Glossary

A

acetylene: A colorless gas with a very distinctive, nauseating odor that is highly combustible when mixed with oxygen. Unstable at pressures above 15 psi. Used in oxyacetylene welding. See *oxyacetylene welding.*

acoustic emission testing (AE): A proof test that consists of detecting acoustic signals produced by plastic deformation or crack formation during mechanical loading or thermal stressing of metals.

acrylic: A one-part UV (heat-cure) or two-part adhesive that can be used on a variety of materials.

actual throat: The shortest distance from the face of a fillet weld to the weld root after welding. See *weld face.*

adhesive bonding: The joining of parts with an adhesive placed between the faying (mating) surfaces, which produces an adhesive bond.

adhesive wear: The removal of metal from a surface by welding together and subsequent shearing of minute areas of two surfaces that slide across each other under pressure.

air carbon arc cutting (CAC-A): A cutting process in which the cutting of metals is accomplished by melting with the heat of an arc between a carbon electrode and the base metal.

air cut time: The time that a piece of equipment spends in the nonproductive activity of moving from one weld to another.

alignment marker: A center punch mark made across the joint in various locations.

alloy: Metal that consists of more than one chemical element, with at least one of the elements being a pure metal.

alteration: Any repair that does not restore a mechanical component to its original design.

alternating current (AC): An electrical current that has alternating positive and negative values. See *current.*

ammeter: An instrument that measures amperage (amperes).

amperage: The quantity of electricity measured.

ampere (amp or A): A unit of measure for electricity that expresses the quantity, or number, of electrons flowing through a conductor per unit of time. See *conductor.*

anaerobic adhesive: A one-part adhesive or sealant that cures due to the absence of air which has been displaced between mated parts.

angle beam: A vibrating pulse wave traveling other than perpendicular to the surface.

annealing: Heat treatment process that softens a metal by heating it to a suitable temperature, holding it at that temperature, and cooling it at a suitable rate.

arc blow: A deflection of the welding arc by magnetic forces that occur along the electric flow.

arc strike: A discontinuity that results from arcing of the electrode and consists of any localized remelted metal, heat-affected metal, or change in the surface profile of any base metal.

arc voltage (working voltage): The voltage present after an arc is struck and maintained.

arc welding (AW): A group of processes that produce coalescence of the metals by heating them with an electric arc.

armature: The part of the generator that rotates with the shaft and delivers the electricity.

arrowhead: A termination of the carrier line in the shape of an arrowhead.

arrow side: The surface that is in the direct line of vision of the welder.

artifact: A nonrelevant indication that appears on a radiograph.

A-scan presentation: A method of data presentation using a horizontal base line that indicates distance or time, and a vertical deflection from the base line that indicates relative amplitude of the returning signal.

autogenous weld: A fusion weld made without filler metal.

auto-refrigeration: Cooling that occurs when gas expands, as in the sudden release of gas from a pipe or piece of equipment.

axis: Straight line around which a geometric figure is generated.

B

backfire: A quick recession of the flame into the welding tip, typically followed by extinction of the flame.

backgouging: The removal of weld metal and base metal from the weld root side of a welded joint to facilitate complete fusion and complete joint penetration when welding on that side is completed.

backhand welding: A welding technique in which the torch is directed opposite to the progress of welding.

backing symbol: Supplementary symbol indicated by a rectangle on the opposite side of the groove weld symbol on the reference line. See *supplementary symbol.*

backing weld: A weld made at the back of a single groove weld which is deposited before any welding on the opposite side is done.

backlighting: A lighting method that uses a diffused light source to eliminate or soften shadow detail.

back (transverse) pitch: Distance from the center of one row of rivets to the center of the adjacent row of rivets. See *rivet.*

back-step welding: A welding process in which weld passes are made in the direction opposite to the progress of welding.

back-to-back positioning: A mechanical restraint method that places identical weldments back-to-back and clamps them together.

back weld: A weld made in the weld root opposite the face of the weld.

bake-out: A temperature-control process used on a casting to remove hydrogen and other contaminants that could cause cracking during welding.

balloting: A formal method of documenting and voting upon the reviewers' suggestions.

bar: Round-, square-, or rectangular-shaped structural steel. See *structural steel.*

base metal: The metal or alloy that is to be welded.

base metal material specification: The chemical composition or industry specification of the base metal.

base metal thickness range: A procedure qualification variable that indicates the range of base metal thicknesses covered in the procedure qualification record.

base metal weldability classification: An alphanumeric system that groups base metals with similar welding characteristics.

bead: Narrow layer or layers of metal deposited on the base metal as an electrode melts. See *base metal* and *electrode.*

beam: I-shaped structural steel. See *structural steel.*

bending strength: A combination of tensile and compressive forces, and is a property that measures resistance to bending or deflection in the direction that the load is applied.

bending stress: See *flexural stress.*

bend test: A destructive test used to determine the ductility of a weld by bending a welded specimen around a standardized mandrel.

bevel: Sloped edge of an object running from surface to surface.

binocular microscope: A light microscope that provides a low-magnification, three-dimensional view of the surface.

biprism: Two uniaxial double-refracting crystals.

bird nesting: The tangling of welding wire in the drive roll as a result of misalignment between the drive roll and the liner.

blend grinding: A mechanical repair method in which a thinned, pitted, or cracked region of a part is smoothed to create a gentle transition with the unaffected surface.

blind hole: Drilled hole that does not pass through.

blind rivet: Rivet with a hollow shank that joins two parts with access from one side. See *rivet* and *shank.*

bloom: A slight haze that appears on the surface of the specimen and is evidence of the first appearance of the microstructure.

bourdon tube: A coiled fluid-containing tube that straightens out as the internal pressure on the fluid is increased.

brazed joint tension shear test: A shear test that determines the strength of filler metal in a brazed joint.

braze welding (BW): A joining process that produces a coalescence of metals with filler metals that begin to melt at temperatures above 840°F (450°C), below the melting point of the metals joined, and in which the filler metal is not distributed into the joint by capillary action.

brazing (B): A group of joining processes that produce a coalescence of metals using nonferrous filler metals that have a melting point below that of the base metal.

brazing symbol: Graphic symbol that shows braze locations and specifications on prints.

brazing temperature range: The temperature range within which the base metal is heated to enable the filler metal to wet the base metal and form a brazed joint.

break line: Line that shows internal features or avoids showing continuous features.

brightfield illumination: An illumination process in which the surface features perpendicular to the optical axis of the microscope appear the brightest.

Brinell hardness test: An indentation hardness test that uses a machine to press a 10 mm diameter, hardened steel ball into the surface of a test specimen.

brinnelling: Localized plastic deformation or surface denting caused by repeated local impact or overload.

brittleness: Lack of ductility in a metal. See *ductility.*

broken-out section: Partial section view which appears to have been broken out of the object. See *section view.*

buildup lighting: A lighting method that combines (adding or deleting) light sources to achieve the desired lighting effect.

burst: A complex branching of the carrier line.

buttering: A surfacing weld variation that applies surfacing metal on one or more joint surfaces to provide compatible base metal for subsequent completion of the weld.

butt joint: A weld joint in which two workpieces are set approximately level to each other and are positioned edge-to-edge. See *weld joint.*

C

calibration block: A piece of material of specified composition, heat treatment, geometric form, and surface finish, by which ultrasonic equipment can be assessed and calibrated for the examination of material of the same general condition.

calibration standard: A calibration block or a reference block.

capillary action: The force that distributes liquid filler metal through surface tension between the faying surfaces of the joint.

carbon equivalent: A formula based on the chemical composition of a steel, which provides a numerical value to indicate whether preheat and postheating are required.

carburizing: Case-hardening process for low-carbon steels that uses an environment with sufficient carbon potential and a temperature above the upper critical temperature. See *case hardening.*

carburizing flame: A reducing flame in which there is an excess of fuel gas.

carrier line: An incandescent (glowing) streak that traces the trajectory (path) of each particle (spark).

cartesian coordinate system: A system of locating points in space defined by perpendicular planes.

case hardening: Process of hardening low-carbon or mild steels by adding carbon, nitrogen, or a combination of carbon and nitrogen to the outer surface, forming a hard, thin outer shell.

cast: Metal heated to its liquid state and poured into a mold, where it cools and resolidifies.

casting alloy: Alloy poured into a sand or permanent metal mold. See *alloy.*

cavitation: Surface damage caused by collapsing vapor bubbles in a flowing liquid.

certificate of analysis (COA): See *mill test report.*

certificate of compliance (COC): A statement by a manufacturer, without supporting documentation, that the supplied metal meets specifications.

certification: A notarized statement provided by a supplier verifying that a product meets the specification under which it is sold.

chamfer: Sloped edge of an object running from surface to side. See *edge.*

channel: C-shaped structural steel used in conjunction with other structural shapes as support members or combined to serve as an I beam. See *structural steel.*

charpy: Impact test specimen supported horizontally between two anvils with the pendulum allowed to strike opposite the notch.

Charpy V-notch test: A toughness test that uses the energy produced by a dynamic load, and measures the energy needed to break a small machine-notched test specimen.

check valve: A valve that allows the flow of liquid or gas in one direction only.

chemical analysis: A destructive quantitative identification method that requires removal of a small sample (1 g to 2 g) of metal for chemical analysis of its constituent elements.

chemical inhomogeneity: Any disturbance in the chemical composition gradient of a metal.

chemical polishing: A polishing process that uses chemical reactions to remove the rough peaks on the specimen surface.

chemical properties: Properties of metals that are directly related to molecular composition and pertaining to the chemical reactivity of metals and the surrounding environment.

chemical spot testing: A semi-quantitative identification method that uses chemicals that react when placed on certain types of metals.

chill plate: A metal plate used to prevent overheating during welding.

chisel testing: A qualitative identification method that identifies metal by the shape of the chips it produces.

circular magnetization: A concentric magnetic field produced by a straight conductor, such as a piece of wire, carrying an electrical current.

code: A type of standard that is mandatory and is used by a jurisdictional body.

coefficient of thermal expansion: The change in unit dimension, such as length, caused by a 1° rise in temperature.

cold crack: A crack that develops after solidification is complete.

cold mechanical repair: A mechanical repair method that consists of spanning a crack in a failed part with structural repair components anchored into sound base metal on both sides of the crack.

cold worked: Metal that is hammered, rolled, or drawn through a die.

color-coding: An identification marking that consists of colored stripes painted on one end of metal to allow for permanent storage or temporary storage and subsequent retrieval from a metal service center or a user's storeroom.

color test: Metal identification test that identifies metals by their color.

combined weld symbols: Weld symbols used when the weld joint, weld type, and welding operation require more information than can be specified with one weld symbol. See *weld symbol*, *weld joint*, and *weld type*.

commutator: The part of an armature that connects the armature to the insulated copper bars on which the brushes ride.

compression: Stress caused by two equal forces acting on the same axial line to crush an object. See *stress* and *axis.*

compressive strength: The ability of a metal to resist being crushed.

concave: Curved inward.

concave root surface: A depression in the weld extending below the surface of the adjacent base metal caused by an underfill in the root pass of a weld.

conductor: Any material through which electricity flows easily.

confined space: A space large enough and so configured that an employee can physically enter and perform assigned work, has limited or restricted means for entry and exit, and is not designed for continuous employee occupancy.

constant-current welding machine: A welding machine in which a steady supply of current is produced over a wide range of welding voltages caused by changes in arc length.

constant pitch: Standard screw thread series with a set number of threads per inch regardless of diameter. See *standard series.*

constant potential: Generation of a stable voltage regardless of the current output produced by the welding machine.

consumable insert: Spacer that provides proper opening of a weld joint and becomes part of the filler metal during welding. See *weld joint.*

consumable insert symbol: Supplementary symbol indicated by a square on the opposite side of a groove weld on the reference line. See *supplementary symbol* and *groove weld.*

continuous magnetization method: An MT examination technique in which the magnetic particles are applied while the magnetizing force is maintained.

contour symbol: Supplementary symbol indicated by a horizontal line or arc parallel to the weld symbol, which specifies the shape of the completed weld. See *supplementary symbol* and *weld symbol.*

convex: Curved outward.

cooling rate: The rate of temperature change of a weld joint over time from the welding temperature to room temperature.

corner joint: A joint formed when two workpieces are positioned at an approximate right angle in the shape of an L.

corrosion: Combining metals with elements in the environment that leads to deterioration of the metal.

corrosion allowance: An additional thickness of metal above the design thickness that allows for metal loss from corrosion or wear without reducing the design thickness.

counterbored hole: Enlarged and recessed hole with square shoulders.

counterdrilled hole: Hole with a cone-shaped opening below the outer surface.

countersink: Tool that produces a countersunk hole. See *countersunk hole.*

countersunk hole: Hole with a cone-shaped opening or recess at the outer surface. See *countersink.*

couplant: A liquid substance used between the search unit and the test surface to permit or improve the transmission of ultrasonic energy.

cover pass: The final weld pass deposited.

crack: A fracture-type discontinuity characterized by a sharp tip and a high ratio of length to width, and width to opening displacement.

crater: A depression in the base metal that is made by the welding heat source at the termination of the weld bead. See *base metal.*

creep: Slow plastic elongation that occurs during extended service under load above a specific temperature for that metal. See *strain.*

critical temperature: Temperature above which steel must be heated so it will harden when quenched.

crosschecking: A series of parallel cracks about ½″ apart that occur in brittle deposits (with hardness greater than HRC 50) as they undergo stress relief.

cryogenic properties: Ability of a metal to resist failure when subjected to very low temperatures.

crystal (transducer): The piezoelectric element in a search unit that converts electrical energy to ultrasonic energy and vice versa.

crystal structure: A specific arrangement of atoms in an orderly and repeating three-dimensional pattern.

cubic foot: 1′-0″ x 1′-0″ x 1′-0″ or 1728 cu in.

cubic inch: 1″ x 1″ x 1″ or its equivalent.

Curie temperature: The temperature of magnetic transformation, above which a metal is nonmagnetic, and below which it is magnetic.

curing: A process that converts the adhesive from its applied condition to the final solid state.

current: The amount of electron flow through an electrical circuit. See *conductor.*

cutting plane line: Line that shows where an object is imagined to be cut in order to view internal features.

cyaniding: Process of hardening low-carbon steel by heating it in sodium cyanide or potassium cyanide.

cyanoacrylate adhesive: A one-part adhesive that cures instantly by reacting to trace surface moisture to bond mated parts.

cyclical load: A load that varies with time and rate, but without the sudden change that occurs with an impact load.

D

darkfield illumination: An illumination process that illuminates the specimen at sufficient obliqueness (a narrow angle to the surface) so that the contrast is completely reversed from that obtained with brightfield illumination.

defect: One or more indications whose aggregate size, shape, orientation, location, or properties fail to meet the acceptance criteria of the applicable fabrication code or standard.

demagnetization: The elimination or reduction of residual magnetism created by MT.

density testing: A semi-quantitative identification method that measures the density of an unknown metal.

depth of fusion: Distance from the fusion face to the weld interface. See *fusion face* and *weld interface.*

derating: A lowering of the current output level of an AC welding machine when being used for GTAW.

design thickness: The thickness of metal required to support the load on a part.

destructive testing: Any type of testing that damages the test part (specimen).

developer: A material that is applied to the test surface to accelerate bleedout and enhance the contrast of indications.

developing time: The elapsed time between the application of the developer and the examination of the part.

diffraction: A modification of light in which the rays appear to be deflected to produce fringes of parallel light and dark colored bands.

diffused light: A lighting source that uses a semi-opaque screen (such as ground glass) to diffuse the light source, reduce glare, and soften harsh details.

dilution: A change in the composition of welding filler metal in the weld deposit caused by melted base metal.

direct current (DC): An electrical current that flows in one direction only. See *current.*

direct current electrode negative (DCEN): Flow of current from electrode (–) to work (+). See *electrode.*

direct current electrode positive (DCEP): Flow of current from work (–) to electrode (+). See *electrode.*

dissimilar metal welding: The joining of two metals of different composition using a compatible filler metal to ensure the weld meets required properties.

distortion: The undesirable dimensional change of a fabrication.

distribution piping: Carbon-steel, standard-size pipe of small diameter that conveys products from intermediate facilities to consumers.

double-bevel-groove weld: Groove weld having joint members beveled on both sides with the weld made from both sides. See *groove weld.*

double-flare-bevel-groove weld: Groove weld having two radiused joint members with the weld made from both sides. See *groove weld.*

double-flare-V-groove weld: Groove weld having radiused joint members with the weld made from both sides. See *groove weld.*

double-groove weld: A groove weld that is made from both sides. See *groove weld.*

double-J-groove weld: Groove weld having joint members grooved in a J shape on both sides with the weld made from both sides. See *groove weld.*

double-square-groove weld: Groove weld having square-edged joint members with the weld made from both sides. See *groove weld.*

double-U-groove weld: Groove weld having joint members grooved in a U shape on both sides with the weld made from both sides. See *groove weld.*

double-V-groove weld: Groove weld having joint members angled on both sides with the weld made from both sides. See *groove weld.*

downhill welding: Welding with a downward progression. See *vertical welding.*

drag: Lag between the top of the cut and the bottom as cutting proceeds.

drag angle: The angle where the electrode is pointing in the direction opposite of welding.

drill: Round hole in a material produced by a twist drill.

dry magnetization method: An MT examination technique in which the magnetic particles are in a dry powder form.

ductility: A measure of the ability of a metal to yield plastically under load, rather than fracture.

dunnage: A series of steel I-beams parallel to one another.

duty cycle: The percentage of time during a specified test period that a welding machine can be operated at its rated load without overheating.

dwell time: The total time penetrant is in contact with the component surface, including application and drain times.

dynamic electricity: Electricity in motion in an electric current. See *current.*

E

ear muffs: A device worn over the ears to reduce the level of noise reaching the eardrum.

earplugs: A device inserted into the ear canal to reduce the level of noise reaching the eardrum.

eddy current: An electrical current caused to flow in a conductor by the time or space variation, or both, of an applied magnetic field.

edge: Intersection of two surfaces.

edge joint: Weld joint formed when the edges of two or more parallel or nearly parallel workpieces are joined. See *weld joint.*

edge preparation: The preparation of the workpiece edges by cutting, cleaning, or other methods.

effective throat: The minimum distance between the weld face and the weld root, minus convexity.

elastic deformation: Ability of a metal to return to its original size and shape after loading and unloading.

elastic limit (yield): The maximum stress to which a material is subjected without any permanent strain remaining after stress is completely removed.

electrical circuit: Path taken by electric current flowing from one terminal of the welding machine, through a conductor, and to the other terminal. See *current* and *conductor.*

electrical conductivity: The rate at which electric current flows through a metal.

electrical properties: Ability of a metal to conduct or resist electricity or the flow of electrons.

electrical resistivity (resistivity): The electrical resistance of a unit volume of a material.

electrical resistivity testing: A semi-quantitative identification method that uses differences in electrical resistivity to identify metals.

electrode: A component of the welding circuit that conducts electrical current to the weld area. See *weld bead.*

electrode angle: The angle at which the electrode is held during the welding process.

electrode holder: A handle-like tool that holds the electrode during welding. See *electrode.*

electrogas welding (EGW): A welding process that uses an arc between a filler metal electrode and the weld pool, using approximately vertical welding and a backing bar to control the molten weld metal.

electrolytic polishing: A polishing process in which the mount is the anode (connected to the positive terminal) in an electrolytic solution and current is passed from a metal cathode (connected to the negative terminal).

electromagnetic examination (ET): An NDE method that uses electromagnetic energy having frequencies less than visible light to yield information on the quality of the part being tested.

electron beam welding (EBW): A welding process that produces coalescence with a concentrated beam, composed primarily of high-velocity electrons, impinging on the joint.

electroplating: The application of a thin, hard chrome coating to repair minor damage.

embrittlement: The complete loss of ductility and toughness of a metal, so that it fractures when a small load is applied.

epoxy: A two-part adhesive that cures when resin and hardener are combined.

equipment calibration standard: A test piece that contains typical discontinuities that demonstrate that calibration equipment is detecting the discontinuities for which the part is being inspected.

erosion (low-stress abrasion): A form of abrasive wear in which the force of an abrasive and the surface causes the removal of surface material.

erosion-corrosion: The detrimental effect of velocity or turbulence in a corrosive environment.

essential variable: A welding qualification variable which, if altered, shall be considered to affect the mechanical properties of the weld.

etching: The controlled selective attack on a metal surface for revealing the microstructural detail of a polished specimen.

examiner: A person who is qualified, or qualified and certified, to conduct certain types of NDE processes.

excess weld reinforcement: Weld metal built up in excess of the quantity required to fill a joint.

explosion welding (EXW): A welding process that produces a weld by extreme impact of the metals through controlled detonation.

F

face reinforcement: Reinforcement on the same side as the welding. See *filler metal.*

failure-critical member: A tension member or component whose failure would likely result in collapse of the structure.

failure modes and effects analysis: A failure analysis process that provides a diagnosis of the technical cause of failure using experience gained from previous failures.

false indication: An NDE indication interpreted to be caused by a discontinuity at a location where no discontinuity actually exists.

fast-fill electrode: An iron powder electrode that has a soft arc and fast deposit rate. See *electrode.*

fast-freeze electrode: An electrode that produces a snappy, deep-penetrating arc and fast-freezing deposit. See *electrode.*

fatigue: Failure of a material operating under alternating (cyclic) stresses at a value below the tensile strength of the material.

fatigue strength: Property of a metal to resist various kinds of rapidly alternating stresses. See *stress.*

faying surface: Part of the joint member which is in full contact prior to welding. See *capillary action.*

ferromagnetic material: A material that can be magnetized or strongly attracted by a magnetic field.

ferrous metal: Any metal with iron as a major alloying element.

field rivet: Rivet placed in the field. See *rivet.*

field weld symbol: Supplementary symbol indicated by a triangular flag rising from the intersection of the arrow and reference line, which specifies the welding operation is to be completed in the field at the location of final installation. See *supplementary symbol.*

file testing: A qualitative identification method in which a file is used to indicate the hardness of steel compared with that of the file.

filler metal: Metal deposited in a welded, brazed, or soldered joint during the welding process.

filler metal approval: The process of testing samples of as-received filler metal to certify conformance to a specification.

filler metal quantity: The deposited weld metal thickness range for groove or fillet welds.

filler metal specification: Identification of filler metal by AWS number or other specification designation.

filler metal usability classification: An alphanumeric method of grouping filler metals with similar characteristics.

fillet weld: A weld type of approximately triangular cross section joining two surfaces at approximately right angles. See *weld type.*

fillet weld break test: A break test in which the specimen is tested with the weld root in tension.

fillet weld leg: Distance from the joint root to the weld toe. See *joint root.*

fillet weld leg size: Dimension from the root of a weld to the toes of a weld after welding. See *fillet weld leg.*

fillet weld shear test: A shear test in which a tensile load is placed on a fillet weld specimen so that the load shears the fillet weld in a longitudinal or a transverse direction.

fill-freeze electrode: An electrode that has a moderately forceful arc and deposit rate. The rate is between those of the fast-freeze and fast-fill electrodes. See *electrode.*

fill lighting: A lighting method that uses a small region of a brighter light to increase detail on a dark area of a subject.

fitting: Standard connection used to join two or more pieces of pipe.

fit-up: The positioning of pipe with other pipe or fittings before welding.

fixed automation system: A system that uses machines designed for a single production function.

fixture: A device used to maintain the correct positional relationship between workpieces as required by print specifications.

flame spraying: A thermal spraying process that uses an oxyfuel gas flame as a source of heat for melting the coating material.

flanged joint: A joint in which one of the joint members has a flanged edge at the weld joint.

flash arrestor: A safety device that prevents an explosion or a backfire in the torch or torch head from reaching the regulator and the acetylene cylinder.

flashback: A recession of the flame into or back of the mixing chamber in a flame torch or flame spray torch.

flashlight: A lighting source that provides a pulse of very intense light.

flash welding (FW): A resistance welding process that produces a weld at the faying surfaces of a joint by the intense heat of an arc that occurs when the workpieces are contacted and by the application of pressure after heating has been substantially completed.

flaw (indication): A discontinuity that can be detected through NDE techniques.

flexible automation system: A system that uses programmable movements of the torch and sometimes the workpiece.

flexural (bending) stress: Stress caused by equal forces acting perpendicular to the horizontal axis of an object.

fluidity: A measure of the viscosity or flowability of a liquid or molten solid.

fluorescence: The ability of certain atoms to emit light when they are exposed to external radiation of shorter wavelengths.

flush patch: A patch applied to a component that provides a smooth transition between the component and the patch.

flux: A material that hinders or prevents the formation of oxides and other undesirable substances in molten metal.

flux cored arc welding (FCAW): An arc welding process that uses a tubular electrode with flux in its core.

forced cooling: Rapid cooling of a solidified weld joint between passes using water.

forehand welding: A welding technique in which the torch is directed toward the progress of welding.

forged: Metal formed by a mechanical or hydraulic press with or without heat.

forge welding (FOW): A welding process that produces a weld by heating the metals to welding temperature and applying forceful blows to cause deformation at the faying surfaces.

fork: A simple branching of the carrier line.

foundry mark: An identification marking embossed on the exterior of castings.

fracture test: Metal identification test that breaks the metal sample to check for ductility and grain size. See *ductility.*

frequency: The number of cycles per second in an AC sine wave.

fretting: Surface damage between two materials, usually metal, caused by oscillatory movement between the surfaces.

friction welding (FRW): A welding process that joins two metal parts that rotate or are in relative motion with respect to one another when they are brought into contact and pressure is applied between them.

full skip: One complete reflection of the ultrasonic beam.

fusion: Melting together of filler metal and base metal. See *filler metal* and *base metal.*

fusion face: Surface of the base metal that is melted during welding. See *fusion.*

fusion welding: Welding that uses fusion of the base metal to make a weld.

G

galling: A condition that occurs when excessive friction, caused by rubbing of high spots on the surface, results in localized welding with subsequent spalling (formation of surface slivers) and further roughening of the rubbing surfaces.

gas metal arc welding (GMAW): An arc welding process that uses an arc between a continuous wire electrode and the weld pool.

gas-shielded flux cored arc welding (FCAW-G): An FCAW variation in which the shielding is obtained from both the CO_2 gas flowing from the nozzle and from the flux core of the electrode.

gas tungsten arc spot welding: An arc welding process that produces localized fusion similar to resistance spot welding but does not require accessibility to both sides of the joint.

gas tungsten arc welding (GTAW): An arc welding process in which a shielding gas protects the arc between a nonconsumable (does not become part of the weld) tungsten electrode and the weld area. See *electrode.*

globular transfer: The transfer of molten metal in large droplets from the welding wire to the workpiece across an arc.

gouging: A cutting process that removes metal by melting or burning off a portion of the base metal to form a bevel or groove.

gouging (high-stress abrasion): A severe form of abrasive wear in which the force between an abrasive body and the wearing surface is large enough to macroscopically gouge, groove, or deeply scratch the surface.

grain: Individual crystal in a metal that has multiple crystals. See *crystal.*

grain structure: Pattern of the grains in a metal. See *grain.*

graphitization: The formation of iron carbide that results in loss of ductility.

grinding: The mechanical removal of metal from the surface using hard, brittle grains of an abrasive material.

grip: Effective holding length of a rivet. See *rivet.*

groove face: Surface of the joint member included in the groove of the weld.

groove weld: A weld type made in the groove between the two workpieces to be joined. See *weld type.*

grounding device (ground): Connection between welding cable and weld parts in the welding circuit.

guided bend test: A bend test in which a rectangular piece of welded metal is bent around a U-shaped die and forced into a U shape.

H

hardfacing: Application of filler metals which provide a coating to protect the base metal from wear caused by impact, abrasion, erosion, or from other wear. See *filler metal* and *base metal.*

hardness: The resistance of a material to deformation, indentation, or scratching.

heat-affected zone (HAZ): A narrow band of base metal adjacent to the weld joint whose properties and/or metallurgical structure are altered by the heat of welding. See *base metal* and *mechanical property.*

heating rate: The rate of temperature change of a weld joint over time from room temperature to the welding temperature.

heat input: The amount of heat applied to the filler metal and the base metal surface at the required rate to form a weld pool, plus the additional heat required to compensate for heat that is conducted away from the weld.

heat shaping: The application of localized heating to cause movement of a distorted part and restore its dimensions.

hertz (Hz): The international unit of frequency equal to 1 cycle per second.

high-carbon steel: Steel with a carbon range of 0.45% to 0.75%.

hot crack: A crack formed at temperatures near the completion of solidification.

hot melt adhesive: Thermoplastic material that is applied in a molten state and cures to a solid state when cooled.

hydrogen-assisted cracking: Loss of toughness in steels resulting from hydrogen atoms created at the surface of the metal by corrosion that diffuse into the HAZ and the base metal.

hydrostatic testing (hydrotesting): Proof testing of closed containers such as vessels, tanks, and piping systems by filling them with water and applying a predetermined test pressure.

I

image quality indicator (IQI): A device or combination of devices whose demonstrated image determines radiographic quality and sensitivity.

impact damage: Removal of material from and damage to a surface caused by repetitive collisions or impact between two surfaces.

impact load: Load that is applied suddenly or intermittently. See *load.*

impact strength: Ability of a metal to resist loads that are applied suddenly and often at high velocity.

impact testing: Special testing performed on small, notched specimens, to simulate a stress concentration effect.

inclusion: Entrapped foreign solid material in deposited weld metal, such as slag or flux, tungsten, or oxide.

incomplete fusion: A lack of union (fusion) between adjacent weld passes or base metal.

incomplete penetration: A condition in a groove weld in which weld metal does not extend through the joint thickness.

inert gas: A gas that does not readily combine with other elements.

inspector: A person who is qualified, or qualified and certified, to apply the results of NDE flaw characterization to determine whether the flaws meet the acceptance criteria of the applicable fabrication code or standard.

intergranular penetration: Penetration of molten metal along the grain boundaries of the base metal that leads to embrittlement of the base metal.

intermediate weld pass: A single progression of welding subsequent to the root pass and before the cover pass.

intermittent welding: A stress-reduction technique in which the continuity of the weld is broken by recurring spaces between welds.

intermittent welds: Short sections of fillet welds applied at specified intervals on the weld part. See *fillet weld.*

interpass temperature: Weld area temperature between passes of a multiple-pass weld. See *weld pass.*

interpass temperature control: Maintaining the temperature range within the weld between weld passes until welding is complete.

interstitial element: A chemical element added in small amounts, whose atomic size is significantly less than the major elements present in the metal.

inverter: An electrical device that changes DC current into AC current.

J

joint design: The shape, dimensions, and configuration of the joint.

joint penetration: The depth of the weld metal from the weld face into the joint.

joint root: The portion of a weld joint where joint members are the closest to each other.

K

kerf: The width of the cut metal.

killed steel: Steel that is completely deoxidized during steel production by adding silicon or aluminum in the furnace ladle or to the mold.

L

lamellar tearing: A subsurface terrace and step-like crack pattern in wrought steel base metal oriented parallel to the base metal working direction.

laminar discontinuity: A discontinuity that is relatively thin and flat.

lap joint: A weld joint between two overlapping workpieces in parallel planes. See *weld joint.*

large rivets: Rivets with a shank ½″ or greater in diameter. See *rivet* and *shank.*

laser beam welding (LBW): A welding process that produces coalescence with the heat from a laser beam impinging on the joint.

liquid impingement: Progressive material removal from a surface by the striking action of a liquid.

liquid penetrant examination (PT): An NDE technique that uses dyes suspended in high-fluidity liquids to penetrate solid materials and indicate the presence of discontinuities.

liquidus: The lowest temperature at which an alloy is completely molten.

liquidus temperature: The melting temperature of a filler metal.

load: External mechanical force applied to a component. See *stress.*

load cell: A device that uses the elastic deformation of a spring or diaphragm that is calibrated to indicate the mechanical load applied to the specimen.

longitudinal crack: A crack with its major axis oriented approximately parallel to the weld axis.

longitudinal magnetization: A magnetic field produced when the current-carrying conductor is coiled and the magnetic field is parallel to the axis of the coil.

longitudinal shrinkage: Weld metal shrinkage that occurs parallel to the weld axis.

longitudinal wave: A compression wave that represents wave motion in which the particle oscillation is in the same direction as wave propagation.

low-carbon steel: Steel with a carbon range of .05% to .30%.

low heat input welding: A stress-reduction technique that decreases the amount of heat applied to the weld.

M

machinable electrode: Electrode whose deposits are soft and ductile enough so that they can easily be machined after welding. See *electrode.*

machining: Precise shaping to a desired profile using special tools to remove material.

macroetchants: Deep etchants that are intended to develop gross features such as weld solidification structures.

magnetic field: The space within and around a magnetized part or conductor carrying current in which a magnetic force is exerted.

magnetic leakage field: The magnetic field that leaves or enters the surface of a part at a discontinuity or change in section configuration of a magnetic circuit.

magnetic particle: A finely divided ferromagnetic material that is capable of being individually magnetized and attracted to distortion in a magnetic field.

magnetic particle examination (MT): An NDE method that uses a strong magnetizing current and a finely divided powder to detect defects.

magnetic response testing: A qualitative identification method in which a magnet is laid on the surface of an unknown metal to test for a magnetic force.

magnetism: The ability of a metal to be attracted by a magnet, or to develop residual magnetism when placed in a magnetic or electrical field.

main lighting: A primary lighting method that uses a light source at a vertical angle of 40° to 60° to the subject.

malleability: Ability of a metal to be deformed by compressive forces without developing defects such as those encountered in rolling, pressing, or forging.

manufacturing data report (MDR): A legal document signed by the representatives of the manufacturer and the manufacturer's authorized inspection agency.

margin: Distance from the edge of a plate to the centerline of the nearest row of rivets. See *rivet.*

material safety data sheet (MSDS): Printed material that includes data about every hazardous component comprising 1% or more of a material's content and used by a manufacturer, importer, or distributor to relay chemical hazard information to the employee.

materials nonconformance report: A form created by the receiver of the metal to audit manufacturer paperwork regarding supplied metals.

materials test report (MTR): A certified statement issued by the primary manufacturer indicating the chemical analysis and mechanical properties of the metal.

mechanical bond: The joining of two components by locking, compression, or surface tension.

mechanical property: A property of metal that describes the behavior of metals under applied loads.

mechanical repair: A repair weld process that consists of methods that do not create a metallurgical bond between the restored parts or at the restored surface.

mechanical restraint: A device used to restrict movement and counteract shrinkage stresses that occur during welding.

medium-carbon steel: Steel with a carbon range of .30% to .45%.

melting point: The temperature at which a metal passes from a solid state to a liquid (molten) state.

melt-through: A discontinuity that occurs in butt welds when the arc melts through the bottom of the weld.

metallograph: A metallurgical microscope equipped to photograph microstructures and produce photomicrographs.

metallurgical bond: The joining of two components by atomic fusion.

metallurgical structure: The arrangement of atoms in repeating patterns within a metal.

metallurgy: The study of the influence of crystal and grain structure of metals on the mechanical, physical, and chemical properties of metals.

meter: A device used to measure and indicate the flow of a gas, liquid, or current through a system.

metric equivalent standard: A version of a standard in which all the units are indicated in metric (SI) values.

microanalysis: Chemical analysis of extremely small regions of the specimen surface using tools such as energy-dispersive X-ray analysis or electron probe microanalysis.

microhardness test: A microhardness test is a type of indentation hardness test that uses light loads of less than 200g.

microstructure: The appearance of the metallurgical structure of metals when they are specially prepared to reveal their features.

mill test report (MTR): Certification issued by the primary manufacturer (mill) verifying the chemical analysis and mechanical test properties of stock obtained from a starting ingot or billet of metal. See *certificate of analysis (COA).*

mock-up: A simulation of the repair area on which the welder performs work in the expected position of the repair.

modulus of elasticity: A measure of the stiffness of an object under tension or compression.

multiple-impulse welding: A form of resistance welding in which welds are made with repeated electrical impulses.

N

neutral flame: A flame that has neither oxidizing nor carburizing characteristics.

nil ductility transition (NDT) temperature test: A toughness test that measures the temperature at which the fracture behavior of a metal changes from ductile to brittle in the presence of a stress raiser.

noise reduction rating number (NRR): A number that indicates the noise level reduction in decibels (dB).

Nomarski illumination: An illumination process that illuminates the specimen using polarized light that is separated into two beams by a biprism.

nondestructive examination (NDE): The development and application of technical methods to examine materials or components in ways that do not impair their future usefulness and serviceability.

nonessential variable: A qualification variable that may be changed in a WPS without requalification of the WPS.

nonrelevant indication: An NDE indication caused by a discontinuity that, after evaluation, does not need to be rejected.

notch effect: A stress-concentrating condition caused by an abrupt change in section thickness or in continuity of the structure.

O

Occupational Safety and Health Administration (OSHA): A federal agency that requires all employers to provide a safe environment for their employees.

ohm: The basic unit of measurement of resistance and impedance. One ohm is the result of 1 V applied across a resistance that allows 1 A to flow through it.

open-circuit voltage: The voltage produced when the machine is ON and no welding is being done.

open root joint: An unwelded joint that does not use backing or consumable inserts.

optical emission spectrometer: An instrument used for optical emission spectroscopy that is placed on the surface of an unknown metal.

optical emission spectroscopy: A semi-quantitative identification method that separates and analyzes the light emitted from an unknown metal surface when it is arced by an electric current.

other side: The opposite surface of the joint.

overheating: Microstructural damage or change caused by cutting operations.

overlapping: Extending the weld metal beyond the weld toes or the weld foot.

oxidation: The combination of a metal with oxygen in the air to form metal oxide.

oxidizing flame: A flame in which there is an excess of oxygen.

oxyacetylene welding (OAW): An oxyfuel welding process that uses acetylene as the fuel gas.

oxyfuel cutting (OFC): A group of cutting processes that use high heat temperatures generated by burning a fuel gas in oxygen to accelerate the chemical reaction between oxygen and the base metal to sever and remove the metal.

oxyfuel welding (OFW): A group of welding processes that use heat from the combustion of a mixture of oxygen and a fuel for welding.

P

paperwork: Physical certification or documentation provided by a product manufacturer or supplier.

pass: Each layer of bead deposited on the base metal.

peel test: A shear test in which a specimen is gripped in a vise and then bent and peeled apart with pincers to reveal the weld.

peening: The mechanical working of weld metal using impact blows.

penetrant: A solution or suspension of dye.

permit-required confined space: A confined space that has specific health and safety hazards associated with it.

personal protective equipment: Equipment worn by welders to prevent injury.

photomacrography: The documentation of macroetched samples using photography.

physical failure analysis: A failure analysis process that provides a diagnosis of the technical cause of failure using rigorous analytical methods.

pipe jig: A device that holds sections of pipe or fittings before tack welding.

pitting (spalling): The forming of localized cavities in metal resulting from corrosion, repetitive sliding or rolling surface stresses, or poor electroplating.

plane-strain fracture toughness test: A toughness test that measures the resistance of metals to brittle fracture propagation in the presence of stress raisers such as weld defects.

plasma arc cutting (PAC): A cutting process that uses a constricted arc to remove molten metal with a high-velocity jet of ionized gas.

plasma arc welding (PAW): An arc welding process that uses a constricted arc between a nonconsumable tungsten electrode and the weld pool (transferred arc), or between the electrode and constricting nozzle (non-transferred arc).

plasma spraying: A thermal spraying process in which a plasma torch is used as a heat source for melting and propelling the surfacing material to the workpiece.

plastic strain: Strain that remains permanent after the stress is removed.

plug weld: A weld made in a circular hole in one workpiece, fusing that workpiece to another.

pneumatic testing: A proof test in which air is pressurized inside a closed vessel to reveal leaks.

polarity: The positive (+) or negative (–) state of an object.

polarized illumination: An illumination process that reveals microstructural features in metals that are optically anisotropic.

polarizer: A device into which normal light passes and from which polarized light emerges.

polysulfide adhesive: A one- or two-part adhesive or sealant that cures by evaporation or catalyst.

polyurethane: A one- or two-part adhesive with excellent flexibility that cures by evaporation, catalyst, or heat.

positioner: A mechanical device that supports and moves workpieces for maximum loading, welding, and unloading efficiency.

postheating: The reheating of the weld area to a high temperature, holding for a predetermined time at temperature, and cooling at a specified rate.

prebending: A mechanical restraint method that relies on locating workpieces out of position before welding so that welding shrinkage stresses pull the workpieces back into position.

preheat: The heating of the joint area to a predetermined temperature in order to slow the cooling rate.

prequalified PQR: A welding procedure specification that complies with the stipulated conditions of a particular fabrication standard or code and is acceptable for use under that code without requiring additional qualification testing.

primary weld: A weld that is an integral part of a structure and that directly transfers the load. See *load.*

procedure qualification record (PQR): Documentation of the welding variables used to produce an acceptable test weld and the results of tests conducted on the weld to qualify a WPS.

prod: A set of hand-held electrodes used to transmit the magnetizing current from the source to the material being inspected.

prod method: A wet or dry continuous method in which portable prod-type electrical contacts are pressed against the areas to be examined to magnetize them.

product analysis: A chemical report that a particular metal, such as tubing or piping, is made from a particular heat of metal.

projection weld: A resistance weld type produced by the heat obtained from the resistance to the flow of welding current. See *weld type, fusion,* and *base metal.*

projection welding (PW): A welding process that produces a weld using heat obtained from resistance of the workpiece to the welding current.

proof testing: The application of specific loads to welded structures, without failure or permanent deformation, to assess their mechanical integrity.

proportional limit: The maximum stress at which stress is directly proportional to strain. See *stress.*

pulsed spray transfer: A spray transfer mode in which current is cycled from low to high, at which point spray transfer occurs.

pulse-echo mode: A UT inspection method in which the presence and position of a reflector are indicated by the echo amplitude and time.

pure metal: Metal that consists of one chemical element.

push angle: A travel angle where the electrode is angled to point in the direction of welding.

Q

qualitative identification: Metal identification by a qualified person to confirm the identity of an unknown metal.

R

radiograph: A permanent, visible image on a recording medium produced by penetrating radiation passing through a material being tested.

radiographic examination: The use of X rays or nuclear radiation (gamma rays) to detect various types of internal and external discontinuities in material.

reaming: Enlarging and improving the surface quality of a hole.

recommended practice: A type of standard that provides instructions for performing one or more repetitive technical functions.

rectifier: An electrical device contained within a transformer welding machine that changes AC current into DC current.

red hardness: The capacity to resist softening in the red heat temperature range.

reducing flame: See *carburizing flame.*

reduction: Loss or removal of oxygen during the welding process.

reference block: A test piece of the same material, shape, and significant dimensions as a particular object under examination, and which may contain natural or artificial discontinuities or defects.

reflected light: A lighting source that bounces light off a white card, wall, or ceiling.

reinforcement: Amount of weld metal that is piled up above the surface of the pieces being joined.

relevant indication: An NDE indication caused by a discontinuity that requires evaluation.

rerating: Revision of the allowable design parameters of a mechanical component from the original design arising from formal study of its current condition.

residual magnetization method: An MT examination technique in which magnetic particles are applied after the magnetizing force has been disconnected.

residual stress: Stress that occurs in a joint member or material after welding has been completed, resulting from thermal or mechanical conditions.

resistance: The opposition of the material in a conductor to the passage of electric current, causing the electrical energy to be transformed into heat.

resistance welding (RW): A group of welding processes in which fusion occurs from the heat obtained by resistance to the flow of current through the metals joined.

restraint: A clamp or fixture used to reduce distortion by preventing movement of the weld during cooling, but which does not necessarily reduce residual stress.

retentivity: The ability of a material to retain a portion of the applied magnetic field after the magnetizing force has been removed.

right angle: Angle that contains 90°.

rimmed steel: Steel with little or no deoxidizer addition.

ripple: The shape within the deposited bead caused by the movement of the welding heat source. See *bead.*

rivet: Cylindrical metal pin with a preformed head.

rivet pitch: Distance from the center of one rivet to the center of the next rivet in the same row. See *rivet.*

robot: A programmed path device used to position the torch and at times the workpiece.

Rockwell hardness test: An indentation hardness test that uses two loads, supplied sequentially, to form an indentation on a metal test specimen to determine hardness.

roll welding: A welding procedure that applies heat and pressure to interlock the faying surfaces of the weld.

root bead: A weld bead that extends into or includes part or all of the joint root.

root cause failure analysis: A failure analysis process that determines how to prevent a failure from recurring by understanding how the actions of humans or systems may have led to the technical cause of the failure.

root edge: Weld face that comes to a point and has no width. See *weld face.*

root face: The portion of the groove face within the joint root.

root opening: The distance between joint members at the root of the weld before welding.

root pass: The initial weld pass that provides complete penetration through the thickness of the joint member. See *weld pass* and *penetration.*

root reinforcement: Reinforcement on the side opposite the one on which welding took place. See *filler metal.*

root surface: Surface of the weld on the opposite side of the joint on which welding was done.

rough polishing: A polishing process that is performed on a series of rotating wheels covered with a low-nap cloth (cloth containing a small amount of fiber).

run-off tab: A piece of metal of the same composition and thickness as the base metal that is tacked to the weld to allow the weld to be completed on it.

S

screw thread series: Groups of diameter-pitch combinations.

sealant: A product used to seal, fill voids, and waterproof parts.

seam weld: A continuous weld between overlapping workpieces in which coalescence produces a continuous seam or series of overlapping spot-welds. See *weld type, fusion,* and *spot weld.*

search unit (probe): An electroacoustic device for transmitting or receiving ultrasonic energy, or both.

secondary weld: A weld used to hold joint members and subassemblies together.

section view: Interior view of an object through which a cutting plane has been passed. See *cutting plane line.*

segregation: Any concentration of alloying chemical elements in a specific region of a metal. See *base metal.*

selective plating: A form of electroplating used for touch-up repairs on worn or damaged parts.

self-shielded flux cored arc welding (FCAW-S): An FCAW variation in which shielding gas is provided exclusively by the flux within the electrode core.

semikilled steel: Steel in which deoxidizers only partially kill the oxygen-carbon reaction.

semi-quantitative identification: Metal identification by applying a physical stimulus to an unknown metal to produce a signal that is interpreted against a set of standards.

sensitization: Precipitation of chromium carbides in stainless steels from exposure to high temperatures, as in welding, typically in the HAZ.

servomotor: An AC or DC motor with encoder feedback to indicate how far the motor has rotated.

shank: Cylindrical body of a rivet. See *rivet.*

sheared plate: Plate that is rolled between horizontal and vertical rollers and trimmed on all edges.

shearing: The parting of material when one blade forces the material past an opposing blade.

shear strength: Ability of a metal to withstand two equal forces acting in opposite directions.

shear stress (shear): Stress caused by two equal and parallel forces acting upon an object from opposite directions. See *stress.*

sheet: Structural steel $\frac{3}{16}''$ or less used to cover large expanses of a structure. See *structural steel.*

shielded metal arc welding (SMAW): An arc welding process in which the arc is shielded by the decomposition of the electrode coating.

shop rivet: Rivet placed in the shop. See *rivet.*

short circuiting transfer: A metal transfer mode in which molten metal from consumable welding wire is deposited during repeated short circuits. See *electrode.*

shrinkage stress: Stress that occurs in weld filler metal as it cools, contracts, and solidifies.

silicone: A one- or two-part adhesive or sealant that cures by evaporation or catalyst.

single-bevel-groove weld: Groove weld having one joint member beveled, with the weld made from that side. See *groove weld.*

single-flare-bevel-groove weld: Groove weld having one straight and one radiused joint member, with the weld made from one side. See *groove weld.*

single-flare-V-groove weld: Groove weld having radiused joint members, with the weld made from one side. See *groove weld.*

single-groove weld: A groove weld made from one side only. See *groove weld.*

single-J-groove weld: Groove weld having joint members grooved in a J shape on one side, with the weld made from the grooved side. See *groove weld.*

single-square-groove weld: Groove weld having square-edged joint members, with the weld made from one side. See *groove weld.*

single-U-groove weld: Groove weld having joint members grooved in a U shape on one side, with the weld made from the grooved side. See *groove weld.*

single-V-groove weld: Groove weld having both joint members angled on the same side, with the weld made from the grooved side. See *groove weld.*

slag inclusions: Small particles of slag (cooled flux) trapped in the weld metal which prevent complete penetration.

sleeving: A weld repair method that applies surfacing to badly worn shafts by welding snug-fitting semicircular forms to cover the shaft surface.

slope: The shape of the volt-amp curve on a GMAW welding machine.

slot weld: A weld type made in an elongated hole in one workpiece, fusing that workpiece to another. See *weld type.*

slurry: A mixture of solid particles in a liquid.

slurry erosion: The progressive loss of material from a surface caused by slurry moving over the surface.

soldering (S): A group of joining processes that produce a coalescence of metals with nonferrous filler metals having a melting point below that of the base metals. See *filler metal* and *base metal.*

soldering copper: A tool that consists of a copper or steel heating tip fastened to a rod with a wooden handle.

solidification temperature: Temperature at which the atoms of a metal assume their characteristic crystal structure. See *crystal.*

solid particle impingement: Wearing away of a surface by repeated impacts from solid particles.

solidus: The highest temperature at which an alloy is completely solid.

solidus temperature: The highest temperature that a metal can reach and remain in a solid state.

solvent-base adhesive: A one-part adhesive with a rubber or plastic base that cures by solvent evaporation.

space lattice: Uniform pattern produced by lines connected through the atoms.

spacer symbol: Supplementary symbol indicated by a rectangle centered on reference line. See *supplementary symbol.*

spark testing: A semi-quantitative identification method that identifies metals by the shape, length, and color of the spark produced when the metal is held against a grinding wheel rotating at high speed.

spatter: A discontinuity that occurs when metal particles are expelled during fusion welding and do not form part of the weld.

special series: Screw thread series with combinations of diameter and pitch not in the standard screw thread series. See *screw thread series.*

specification: A type of standard that indicates the technical and commercial requirements for a product.

specific heat: The ratio of the quantity of heat required to increase the temperature of a unit mass of metal by 1°, compared with the amount of heat required to raise the same mass of water by the same temperature.

spin testing: Proof testing of rotating machinery done by spinning it at speeds above design values to develop desired stresses from centrifugal forces.

splat: A flattened particle that cools rapidly and solidifies as it strikes a metal surface.

spotface: Flat surface machined at a right angle to a drilled hole. See *right angle.*

spotlight: An intense lighting source that uses a single bulb in a reflector.

spot weld: A weld made between overlapping workpieces in which coalescence forms a series of separate circular welds. See *weld type* and *fusion.*

spot-weld tension shear test: A shear test that determines the strength of arc welds and resistance spot welds.

spray and fuse (spraywelding): A two step thermal spray process in which a thermal spray coating is deposited and subsequently fused by heating with a torch or by placing the part in a furnace.

spray transfer: A metal transfer mode in which molten welding wire is propelled axially across the arc in small droplets.

staggered intermittent fillet welds: Intermittent fillet welds that have a staggered pitch and are applied to both sides of a weld joint.

standard: A document that, by agreement, serves as a model for the measurement of a property or the establishment of a procedure.

standard series: Screw thread series of coarse (UNC/UNRC), fine (UNF/UNRF), and extra-fine (UNEF/UNREF) graded pitches and eight series with constant pitches. See *screw thread series.*

starved joint: A joint that contains insufficient adhesive to create an optimum bond.

static electricity: Electricity at rest or electricity that is not moving.

static load: A load that remains constant. See *load.*

stator: The stationary part of a generator that produces a rotating magnetic field.

steel deoxidation: The process of removing a controlled amount of oxygen from steel during steelmaking.

stencil marking: An identification marking that consists of continuous or repeated ink markings on the metal.

stickout: The amount of unmelted electrode extending beyond the end of the gas nozzle when using GMAW and FCAW as the welding process.

stopoff: A material used to outline areas that are not to be brazed.

straight bead: A type of weld bead made without any appreciable weaving motion.

straight beam: A vibrating pulse wave traveling perpendicular to the surface.

strain: The accompanying change in dimensions when a load induces stress in a material. See *stress.*

strength: The ability of a metal to resist deformation from mechanical forces exerted on it.

stress: The internal resistance of a material to an externally applied load. See *strain.*

stress relieving: Process of heating a metal to a suitable temperature, holding it at that temperature to reduce residual stresses, and cooling it slowly to minimize the development of new residual stresses. See *stress.*

strongback: A mechanical restraint device that is attached to one side of a weld joint to hold workpieces in alignment during welding.

structural steel: Steel used in the erection of a structure.

structural weld repair: Restoration of a load-bearing structure by welding to meet performance requirements.

stud weld: A weld type made by joining threaded studs with other parts using heat and pressure. See *weld type.*

submerged arc welding (SAW): An arc welding process that uses an arc between a bare metal electrode and the weld pool.

subresonant vibration: Vibration frequency less than the resonant frequency of the weld.

subsurface deformation: Microstructural damage or change produced by cutting and that occurs below the surface of the specimen.

supplementary essential variable: A qualification variable, for metals where impact testing is required, that requires a new welding procedure specification.

supplementary symbol: Symbol used on welding symbols to further define the operation to be completed.

surface feature: A part of a surface where change occurs.

surfacing: The application of a layer or layers of material to a surface to obtain desired properties or dimensions.

surfacing weld: A weld applied to a surface, as opposed to a joint, to obtain desired properties or dimensions.

surfacing weld repair: The application of a layer, or layers, of weld metal to restore corroded, worn, or cavitated components to extend their useful life.

sweat soldering: A process whereby two surfaces are soldered together without allowing the solder to be seen.

T

tack weld: A weld used to hold workpieces in proper alignment until the final welds are made.

tail: Part of a welding symbol included when a specific welding process, specification, or procedure must be indicated. See *welding symbol.*

teach pendant: The input method that the robot programmer uses to move the robot and create robot programs.

tee: T-shaped structural steel made of I beams cut to specifications by mill or suppliers. See *structural steel.*

tensile strength: A measure of the maximum stress that a material can resist under tensile stress. See *load.*

tensile test: A destructive test that measures the effects of a tensile force on a material.

tensile test machine: A testing machine composed of two major components that are the means of applying the load to the specimen and the means of measuring the applied load.

tension (tensile stress): Stress caused by two equal forces acting on the same axial line to pull an object apart.

tension shear test: A shear test in which a prepared specimen is pulled to failure in a tensile testing machine.

theoretical throat: Distance from the face of a fillet weld to the root before welding. See *fillet weld, weld face,* and *weld root.*

thermal conductivity: The rate which metal transmits heat.

thermal equilibrium: A steady-state condition in which time is available for the diffusion of atoms.

thermal expansion: A measure of the change in dimension of a member caused by heating or cooling. See *metal.*

thermal properties: One of the physical properties of metal. Includes melting point, thermal conductivity, and thermal expansion and contraction.

thermal spraying (THSP): A group of processes in which finely divided metallic or nonmetallic materials are deposited in a molten or semimolten condition to form a coating.

thermoelectric potential sorting: A semi-quantitative identification method that uses measurement of the electric potential generated when two metals are heated.

threaded fasteners: Devices such as nuts and bolts that join or fasten parts together with threads.

through hole: Drilled hole passing completely through the material.

T-joint: A weld joint formed when two workpieces are positioned at approximately 90° to one another in the form of a T.

torch positioner: A fixed-path mechanical apparatus that moves the torch in a specified path.

torch testing: A qualitative identification method that identifies a metal by the melting rate, the appearance of the metal when heat is applied, and the action of the molten metal.

torque: Product of the applied force (P) times the distance (L) from the center of application.

torsion (torsional stress): Stress caused by two forces acting in opposite twisting directions. See *stress.*

torsional strength: The measure of a material's ability to withstand forces that cause it to twist.

toughness: The ability of a metal to absorb energy, such as impact loads, and deform rather than crack or fail catastrophically. See *ductility.*

toughness test: A dynamic test in which a specimen is broken by a single blow and the energy absorbed in breaking the piece is measured in foot-pounds (ft-lb).

transformer: An electrical device that changes voltage from one level to another.

transmission piping: Medium- to high-strength steel, relatively thin-wall and large-diameter, that conveys products from locations of production to intermediate facilities.

transverse crack: A crack with its major axis oriented approximately perpendicular to the weld axis.

transverse shrinkage: Weld metal shrinkage that occurs perpendicular to the weld axis.

travel angle: An angle less than 90° between the electrode axis and a line perpendicular to the weld axis and in a plane determined by the electrode axis and the weld axis.

travel speed: The rate at which the electrode is moved along the weld area. See *electrode.*

tubing: Round-, square-, or rectangular-shaped structural steel. See *structural steel.*

U

ultimate tensile strength: A measure of the maximum stress (load) that a metal can withstand.

ultrasonic examination (UT): An NDE method that introduces ultrasonic waves (vibrations) into, through, or onto the surface of a part and determines various attributes of the material from its effects on the ultrasonic waves.

ultrasonic welding (USW): A welding process that produces a weld by applying high-frequency vibratory energy to workpieces that are held together under pressure.

undercutting: Creating a groove in the base metal that is not completely filled by weld metal during the welding process.

underfill: A discontinuity in which the weld face or root surface extends below the adjacent surface of the base metal.

undesirable microstructure: The creation, through the heat of welding, of microstructures that are preferentially attacked in a corrosive environment.

unified numbering system (UNS): A common embedded designation system that unifies all families of metals and alloys.

union: Fitting consisting of three parts having threads and flanges which draw together when tightened.

universal plate: Plate that is rolled between horizontal and vertical rollers and trimmed only on the ends.

uphill welding: Welding with an upward progression. See *vertical weld.*

upset welding (UW): A resistance welding process that produces a weld on the faying surfaces by the heat obtained from resistance to the flow of current through the surface contact areas while under constant pressure.

user enquiry: A formal procedure developed by standards committees and code-creating organizations to help users interpret issues and offer suggestions.

vacuum box testing: The application of a partial vacuum to one side of a structure and examining for the presence of leaks.

variable load: Load that varies with time and rate, but without the sudden change that occurs with an impact load. See *impact load.*

variable voltage control: A control that spans a range of voltages and is used to set the open-circuit voltage on a welding machine.

vertical weld: A weld with the axis of the weld approximately vertical. See *downhill welding* and *uphill welding.*

very-high carbon steel: Steel with a carbon range of 0.75% to 1.7%.

vibratory stress relief: The application of subresonant vibration during welding to control distortion, or after cooling to provide stress relief.

Vickers hardness test: An indentation hardness test that uses an indenter with a 136° square-base diamond cone, and that may be used to test hardness in the base metal, weld metal, and HAZ.

viscosity: The resistance of a substance to flow in a fluid or semi-fluid state.

visual examination (VT): Application of the naked eye, assisted as necessary by low-power magnification and measuring devices, to monitor welding quality.

visual identification: Metal identification that consists of checking the appearance of the base metal or filler metal for key features that identify the metal type.

volt (V): Unit of measure for electricity that expresses the electrical pressure differential between two points in a conductor. See *conductor.*

voltage: The amount of electrical pressure in a circuit.

voltage drop: The voltage decrease across a component due to resistance to the flow of current. See *current* and *resistance.*

volt-amp curve: A curve that shows how the voltage varies in its relationship to current between the open circuit (where there is static electrical potential but no current is flowing) and short circuit (where the electrode touches the workpiece).

voltmeter: An instrument used to measure voltage.

wallpapering: A weld repair method that uses thin, usually 1/16″, sheets of corrosion-resistant material that are welded to a corroded surface.

water-base adhesive: A one-part adhesive that cures by water evaporation.

weave bead: A type of weld bead made with transverse oscillation.

weaving: A welding technique in which the energy source is moved transversely as it progresses along the weld joint.

weld-all-around symbol: Supplementary symbol indicated by a circle at the intersection of the arrow and reference line, which specifies that the weld extends completely around the joint. See *supplementary symbol.*

weld bead: Weld that results from a weld pass. See *weld pass.*

weld contour: Cross-sectional shape of the completed weld face. See *weld face.*

weld cracks: Linear discontinuities that occur in the base metal, weld interface, or the weld metal. See *base metal* and *weld interface.*

weld defects: Undesirable characteristics of a weld which may cause the weld to be rejected.

weld discontinuity: An interruption in the typical structure of a weld.

welder certification: A written statement that the welder has produced welds meeting a prescribed standard of welding performance.

welder performance qualification: A test that demonstrates a welder's ability to produce welds that meet required standards.

welder registration: The act of approving a copy of the welder's certification document by an appropriate authority.

weld face: The exposed surface of the weld, bounded by the weld toes on the side on which welding was done. See *weld toe.*

weld finish: Method used to achieve the surface finish. See *base metal.*

weld gauge: A device for measuring the size and shape of welds.

welding: The coalescence or joining together of metals, with or without a filler metal, using heat, pressure, or heat and pressure.

welding procedure qualification variable: A condition (parameter) that affects the integrity of a weld joint.

welding procedure specification (WPS): A document providing the required welding variables for a specific application to ensure repeatability by properly trained welders and welding operators.

welding symbol: A graphical representation of the specifications for producing a welded joint.

weld interface: The boundary between the weld metal and the base metal in a fusion weld.

weld joint: The physical configuration at the juncture of the workpieces to be welded.

weld leg: The distance from the joint root to the weld toe.

weld metal: The portion of a fusion weld that is completely melted during welding.

weld overlay: The application of surfacing using a welding process that creates a metallurgical bond with the base metal through melting of the surfacing metal.

weld pass: A single progression of welding along the weld joint.

weld reinforcement: The amount of weld metal in excess of that required to fill the joint.

weld repair: A repair weld process that consists of methods that join failed parts or restore their surface using a welding process.

weld root: The area where filler metal intersects base metal and extends the furthest into the weld joint.

weld symbol: A graphic symbol connected to the reference line of a welding symbol specifying the weld type.

weld throat: Distance through the center of the weld from the face to the root. See *weld face* and *weld root.*

weld toe: The intersection of the base metal and the weld face.

weld type: The cross-sectional shape of the weld after filler metal is added to the joint.

weld width: The distance from toe to toe across the face of the weld.

wet magnetization method: An MT examination technique in which the magnetic particles are suspended in a liquid medium.

whipping: A manual welding technique in which the arc is moved quickly backward and forward as it progresses along the weld joint.

work angle: An angle less than 90° in a line perpendicular to the workpiece and in a plane determined by the electrode axis and the weld axis.

working voltage: See *arc voltage.*

workmanship standard: A section of a joint similar to the one in manufacture in which portions of each successive weld pass are shown.

wraparound guided bend test: A bend test in which a specimen is bent around a stationary mandrel a specified amount to expose weld discontinuities.

X

X-ray fluorescence spectrography (XRF): A nondestructive quantitative identification method that uses a gamma ray beam to identify an unknown metal.

Y

yield point: The location on the stress-strain curve where an increase in strain occurs without an increase in stress.

yield strength: The level of stress within a metal that is sufficient to cause plastic flow.

yoke: A temporary horseshoe magnet made of soft, low-retentivity iron that is magnetized by a small coil wound around the horizontal bar.

yoke method: A dry continuous method of MT for detection of surface discontinuities.

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Using the Welding Skills CD-ROM

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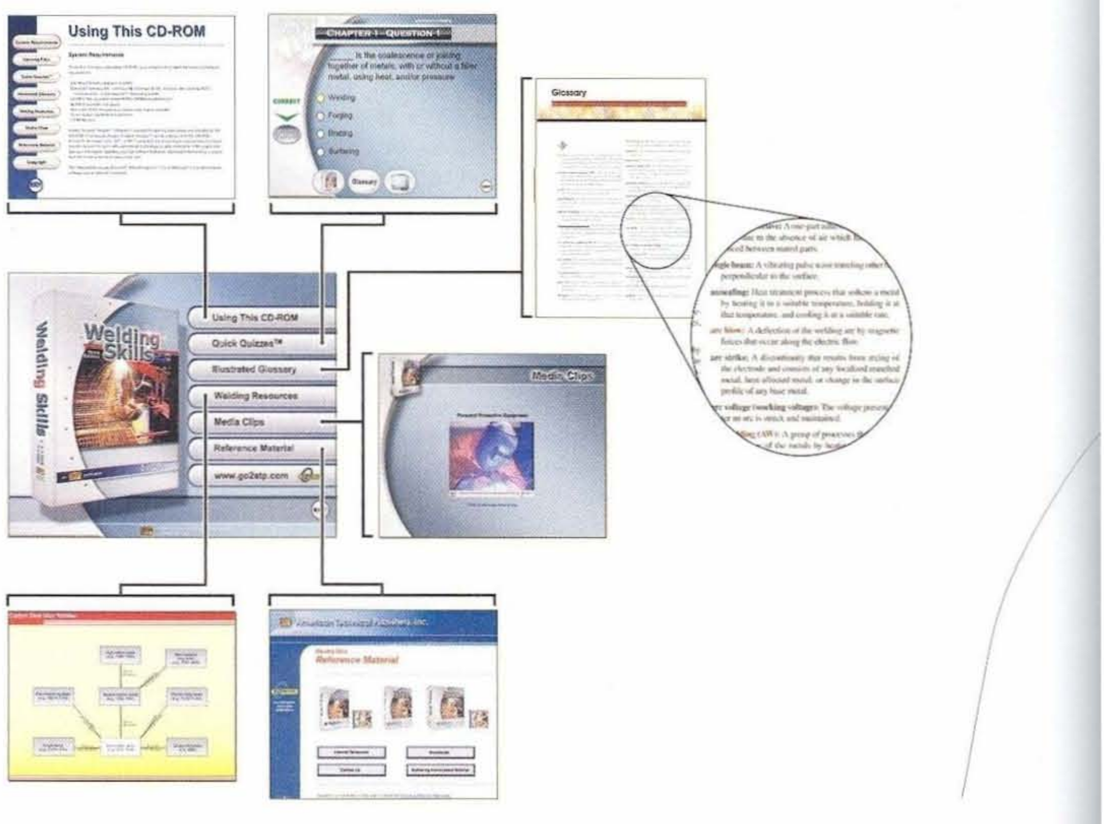

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